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PAPERS

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GUIDEPOST FOR TECHNICAL READERS
MARCH, 1949, *PROCEEDINGS*

Items of value or significance to readers in various fields are here listed. For convenience the distribution is given in terms of the Society's Technical Divisions

(A constant effort is made to supply technical material to Society members, over the entire range of possible interest. In so far as your specialty may be covered inadequately in the foregoing list, this fact is a gage of the need for your help toward improvement.—Ed.)

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AMERICAN SOCIETY OF CIVIL ENGINEERS

Founded November 5, 1852

PAPERS

MULTIPLE-PURPOSE RESERVOIRS

A SYMPOSIUM

Note.—Written comments are invited for immediate publication; to insure publication the last discussion should be submitted by **August 1, 1949**.

INTRODUCTION

In September, 1945, a Joint Committee on Design and Operation of Multiple-Purpose Reservoirs was sponsored by the Hydraulics Division of the Society to study and report on the problems involved in the planning, design, and operation of multiple-purpose reservoir systems for optimum watershed development and utilization. The chairman of this joint committee is Raymond A. Hill, M. ASCE. Six Technical Divisions are represented on the committee; these with their representatives, all corporate members of the Society, are:

Division	Representative
Engineering Economics	Victor H. Cochrane
Hydraulics	Edward H. Sargent
Irrigation	W. G. Sloan
Power	C. N. Phillips
Structural	A. A. Brielmaier
Waterways	Emil P. Schuleen

(Mr. Cochrane died on September 25, 1948.)

It was very quickly found by the committee that there were no fixed principles upon which the design and operation of multiple-purpose reservoir systems could be based; nor was there even any agreement as to what constituted a multiple-purpose reservoir. Some engineers hold that any reservoir used or susceptible of use for more than one purpose should be classified as a multiple-purpose reservoir; others restrict the use of the term, at least for legislative purposes, to such major developments as those constructed by the federal government in the Tennessee Valley and those to be constructed in the Missouri Valley. In general, it has been the thought of the committee that the term "multiple-purpose reservoirs" should include all reservoirs actually designed and operated to serve more than one function and that it should exclude those whose design and operation are controlled by a single function, even though other benefits accrue as by-products.

So marked were the differences between the inchoate philosophies of those responsible for design and operation of multiple-purpose reservoirs that the committee felt it should obtain public expression and discussion of such divergent views. A number of papers were therefore solicited from representatives of most of the federal agencies concerned and from others affected by such projects. Ten of these papers were presented at the Ninety-fourth ASCE Annual Meeting; the remaining three were read at the ASCE Summer Convention in Duluth, Minn., the following summer (1947).

Papers Nos. 1 to 3 of this Symposium concern the development of the underlying principles of design and operation of multiple-purpose reservoirs by the Corps of Engineers, United States Army, by the United States Bureau of Reclamation, and by the Tennessee Valley Authority. Papers Nos. 4 to 7 are directed to the application of such principles and their effect on flood control, on navigation, on irrigation agriculture, and on electric power distribution.

Papers Nos. 8 to 11 describe the activities of certain federal agencies that influence materially the design and operation and evaluation of benefits of multiple-purpose systems. Paper No. 12 is a description of the relationships between the federal government and state governments. Paper No. 13 is a summary and review of the conflicting principles and views outlined in the other twelve.

This Symposium is tendered to the membership in order that there may be appreciation of the lack of agreement among the philosophies of the federal agencies primarily responsible for multiple-purpose reservoirs and of the conflicts between the several functions to be served by such reservoirs. It is the hope and expectation of the Joint Committee on Design and Operation of Multiple-Purpose Reservoirs that discussion of these papers will result in clarification of the issues involved and lead to a better understanding of the interrelated physical and economic factors which determine the optimum design of any multiple-purpose reservoir.

THEIR RELATION TO FLOOD CONTROL AND NAVIGATION

By Malcolm Elliott,[1] M. ASCE

Introduction

For practically all uses except flood control, reservoirs have as their main purpose retention of excess water for future systematic delivery for some beneficial use, generally over a prolonged period. For flood control, however, the main purpose of the reservoir is to keep surplus water out of the rivers during flood periods without regard to any future beneficial use of the water. The storage capacity having been used in decapitating one flood, the reservoir must be drawn down as soon as possible if security against future floods is to be assured. As long as this necessity exists, it is impracticable to schedule releases of the temporarily retained floodwaters over a prolonged period for future use because to do so would incur the risk of another flood arriving while the reservoir does not have capacity to retain it.

On the other hand, reservoirs which are depended on to furnish water for navigation schedule releases over a considerable period. The objective in such cases is not to dispose of the water expeditiously but to conserve it so that all deficiencies during the low-water navigation period will be supplied. Thus, there is a conflict in the use of a reservoir for flood control and the use of a reservoir for navigation. To understand the problem, the reader should first review the roles to be performed by reservoirs for each of the purposes to be considered.

Flood Control Reservoirs

The use of reservoirs as one of several methods of flood control is gaining in popularity and acceptance in the engineering profession. Arguments on levees versus reservoirs are no longer heard. Modern thought accepts the thesis that all methods of flood control--levees, channel enlargement and straightening, floodways, and reservoirs—are important in the solution of over-all flood problems.

Reservoirs are applicable to flood control, or at least are worthy of consideration, where:

1. Adequate reservoir capacity can be obtained;
2. Land or property values within the reservoir area are not excessive in proportion to the prospective benefits;
3. Suitable dam sites exist; and
4. Suitable sites are available, at localities where a substantial proportion of the flood runoff can be collected—if the reservoirs are too far upstream the bulk of the storm causing floods may occur downstream from the reservoir in which case the reservoir will be ineffective; and if they are too far downstream, important areas upstream will be left without protection.

[1] Col., U. S. Army (*Retired*); Cons. Engr., Elliott and Porter, St. Louis, Mo.

Assuming that these conditions have been met adequately, the next important problem connected with flood control is the question of reservoir operation.

The complexities of this problem will probably never be fully comprehended until more experience has been obtained in actual operations. Unless a flood control reservoir has a large surplus capacity, the first concern of the operator should be to disperse the water as soon after it has been collected as possible. Floods can occur in the same basin in rapid succession. If a reservoir is filled by one flood and another flood comes along before the waters collected during the first flood are disposed of, the reservoir not only will not furnish protection from the second flood, but might make it worse. Furthermore, when there are reservoirs on several of the tributaries of a basin, unless the releases are carefully coordinated, there is the possibility that a combination of the releases might create a more serious flood in the main stream than nature could produce without reservoirs.

Navigation Reservoirs

Reservoirs for navigation are of two different types: (1) Headwater or upstream reservoirs whose only function is to retain surplus waters during wet seasons for discharge into the navigable stream below during dry periods or seasons; and (2) reservoirs in the navigation channel itself which form navigable lakes or pools. Fort Peck Reservoir on the Missouri River in Montana and the headwater reservoirs in Minnesota which supply water for the Upper Mississippi River are examples of type (1). The Tennessee Valley Authority (TVA) reservoirs in the main stem of the Tennsesee River which constitute a continuous series of artificial lakes from the mouth to Knoxville, Tenn., are examples of type (2). These two types of navigation reservoirs may be conveniently designated as upstream reservoirs and channel reservoirs, respectively.

Upstream navigation reservoirs are filled with water during the season of surplus runoff, and the water is carefully conserved until the main stream needs supplementary water for the maintenance of navigable depths. Reservoirs are not generally a part of lock and dam navigation projects, because such improvements do not generally need any increase over the natural low-water flow of the river. Only when natural low-water flow is very small (probably less than 1,000 cu ft per sec), or where the waterway crosses a divide from one watershed to another, would water from reservoirs be needed for such projects.

Open-channel developments (that is, those in which navigable depths are obtained by regulation not involving any impoundment of the water in the channel), however, usually require a substantial minimum discharge of water if a navigable channel of suitable width and depth is to be maintained. If the natural discharge is insufficient for this purpose, the deficiency could be made up only by drawing on storage from reservoirs.

These reservoirs would be filled during the season of excessive runoff, of course, and their contents doled out during the low-water season in accordance with deficiencies in natural flow. No attention need be given to retaining enough vacant capacity to catch possible future floods, as is the case with flood control reservoirs.

Upstream navigation reservoirs should not be too far upstream from the navigable section of the river. In general, the closer the reservoir is to where the water is to be delivered to the channel the more efficiently will the water be used. To cite a specific example, Fort Peck Reservoir is not ideally situated for assisting navigation in the lower reaches of the Missouri River and the Mississippi River below the mouth of the Missouri, because of the distance the water must travel before it can be used. The dam is more than 400 miles above the head of the navigation project and 1,200 miles above the mouth of the river. A considerable part of the water released from Fort Peck is used up in valley storage before it reaches the navigable part of the river. Furthermore, in the case of the Mississippi River, the need for additional water must be anticipated by about 3 weeks to allow time for the water to travel from Fort Peck to the river. As a result, the supplementary water may not arrive soon enough; or, if rainfall should occur close to the Mississippi River during the 3-week lag period, the additional water already released might not be required. Both of these conditions tend to extravagance in the expenditure of stored water.

Channel reservoirs or pools vary in character from the low-lift navigation pools in the Ohio and Upper Mississippi rivers to the high-lift lakes in the Tennessee River. The low-lift pools of the Ohio and Mississippi rivers have no flood control significance and further discussion of these devices in a paper dealing with dual-purpose reservoirs is therefore unnecessary. In the case of the Tennessee River, the reservoirs themselves form the navigable waterway. As far as navigation on the Tennessee River is concerned, the reservoirs should contain only enough storage to reach the minimum level necessary to provide navigable depths throughout the length of the reservoirs. The actual storage capacity in these reservoirs over and above this minimum is utilized for flood control and power, and possibly could be diverted for the benefit of navigation in the Ohio and Mississippi rivers below the mouth of the Tennessee River. In regard to the latter possible use, the Tennessee River reservoirs would be classed as upstream reservoirs.

Joint Use of Reservoirs for Navigation and Flood Control

Because of the conflict between uses for navigation and flood control, described previously, it will not generally be possible to build a reservoir primarily for one purpose and to expect that it will automatically and fully serve the other. Deliberate measures must be taken both in design and operation to make sure that both purposes will be served.

Instances may be found in which the aforementioned conflict does not occur. It is understood that in the case of TVA reservoirs the behavior and the time of occurrence of floods are believed to be sufficiently known and consistent enough to warrant filling the reservoirs toward the end of the usual season of excessive runoff and thereafter utilizing the flood control storage space for other purposes.

Thus, dual or multiple use of the same storage space is attained. This procedure would be safe in the Tennessee Valley or elsewhere only if it is certain that no flood can occur after the reservoirs have been filled.

It does not appear safe, however, to assume in every case (or even in the majority of cases) that the habits and the behavior of a river can be predicted with sufficient accuracy to insure that any particular flood is the last one of the season and that flood storage capacity can thereafter be dedicated to some other purpose. This view is consistent with the principles observed by the Corps of Engineers, Department of the Army, in the design of multiple-purpose reservoirs:[2]

> "In the case of a reservoir where storage is to be used jointly for flood control and for other purposes, it is essential that the storage capacity required for flood control be available when needed. Such a condition can exist only where floods always occur during a definite season of the year and where holding the required flood storage capacity empty during the flood season will not affect its availability for other purposes during the seasons when floods do not occur."

Any temptation to encroach on the capacity allocated to one purpose in favor of the other should be vigorously opposed. Floods unfortunately are soon forgotten. Lands may be cultivated, buildings erected, and transportation lines and industry located in the flood plains by people who either have forgotten the preceding major flood or have never experienced a major flood; and when a flood does come enormous damages occur in unprotected areas because of these encroachments. In the period between major floods—years, decades, or generations—it might be very difficult to retain flood storage capacities in reservoirs unused when it is plainly evident that the storage capacity might be used for assistance to navigation, the production of power, or other purposes. This problem is one of the most serious connected with the use of flood control reservoirs for other purposes. It is sufficiently serious to warrant examination and estimates in many, if not all, cases to determine whether the desired dual purposes cannot better and more economically, and reliably, be attained by separate reservoirs allocated to each purpose.

Single-Purpose Reservoirs With Incidental Collateral Purposes

The discussion up to this point has referred to truly dual-purpose reservoirs—that is, to reservoirs that are intended to serve both purposes without emphasis on either one to the disadvantage of the other. There is another type of reservoir development, however, in which the primary purpose might be either flood control or navigation with incidental benefits to the secondary purpose. A reservoir designed solely for the purpose of conserving water for future delivery to a navigable stream will automatically reduce many of the peak flood discharges. Even though such a reservoir may not always produce such incidental benefits—and might even make some floods worse—it is believed that a reservoir built for the primary purpose of furnishing water for navigation, in many instances, will automatically furnish a measure of flood control benefits. Also, single-purpose flood control reservoirs may produce incidental navigation benefits. The limitations on such use of single-purpose reservoirs should be

[2] "Orders and Regulations," Corps of Engrs., U. S. Army, Washington, D. C., May 1, 1940 (revised to February 5, 1945), paragraph 283.19(*b*).

thoroughly known, however, so that the public will not expect too much in the way of incidental benefits. It is particularly important that the public not be assured flood control benefits from a reservoir unless the storage capacity for that purpose is kept available.

Conclusions

Conclusions from the foregoing comments may be stated in four parts:

(1) Dual use of reservoirs for flood control and navigation is practicable under the following conditions—

a. When there are suitable reservoir sites far enough upstream to furnish flood protection to valley land, far enough downstream to control the desired proportion of the valley runoff, and near enough to the navigable waterway so that the water can be economically and promptly delivered thereto; and

b. When there is sufficient storage capacity to serve both purposes.

(2) Unless floods always occur during a definite season of the year, it is unsafe to allocate the same storage space to both navigation and flood control; separate storage zones should be established for each purpose.

(3) Although single-purpose navigation reservoirs may incidentally give some measure of flood control, and vice versa, they cannot be expected to serve both purposes fully. If dual-purpose reservoirs are essential, they must be deliberately provided for in the designs.

(4) Storage space for flood control may remain vacant and unused for many years. The temptation to use it for other purposes may be very strong, but it cannot be so diverted and still remain available for protection against floods.

DEVELOPMENT OF POLICY BY THE BUREAU OF RECLAMATION

By E. B. Debler,[3] M. ASCE

Introduction

In 1902, upon passage of the Reclamation Act, the Reclamation Service was organized as a branch of the United States Geologic Survey and so continued until 1904, when the Reclamation Service was established as an independent branch of the United States Department of the Interior. The name of the agency was changed to Bureau of Reclamation in 1923. The operations of the bureau have been guided by the Reclamation Act of 1902, together with numerous acts amending or supplementing it, of which the Reclamation Project Act of 1939 is probably the most important.

Irrigation

The Reclamation Act of 1902, comprised of ten short sections (of which one has since been repealed), was a relatively simple piece of legislation aimed only to bring federal aid into irrigation development which had been stalled by a combination of poor engineering, inadequate financing, and failure to recognize the problems of converting sagebrush to a going farm. That act nowhere makes reference to any use or control of water other than for irrigation. It contained one important provision, however, and that is the authorization for the withdrawal of public lands from entry for reservoir purposes. Since the western states in which the Bureau was authorized to operate by the Reclamation Act of 1902 still contain much public land, the power of withdrawal has been very useful in setting aside and holding for present and future use a large number of reservoir sites which are or will be useful for power production, flood control, and other purposes, as well as for irrigation.

The paramount purpose of irrigation has been reiterated in public statements of policy by the Department, the Bureau, and their responsible officials, time and again. Supporting legislation is found in such acts as those of April 16, 1906, February 24, 1911, and September 18, 1922. The Boulder Canyon Project Act of December 21, 1928, placed river regulation, improvement of navigation, and flood control ahead of irrigation on that project; but the irrigation purpose was tied to the compact which, with the approval of Congress, states that navigation has ceased to exist. The Central Valley Project in California has a like authorization by the Act of August 28, 1937, but there navigation has a real importance. When the maximum ultimate development of irrigation was threatened by navigation planning and authorizations, the Flood Control Act of December 22, 1944, and the companion River and Harbors Act of the following January effectively established the principle that irrigation is a paramount use throughout western United States, where it is essential to successful agriculture.

[3] Hydr. Engr., U. S. Bureau of Reclamation, Denver, Colo.

The first instance of the recognition of power in Bureau legislation appears in the Act of April 16, 1906, Section V of which authorizes the secretary, where power is necessary for the irrigation of lands, to sell the surplus power produced, for periods not exceeding 10 years. Preference in such sales is given for municipal purposes; and the income is to be credited to the project from which the power is derived. That act and subsequent acts relating to power provide that the production of power must not impair the irrigation efficiency of the project.

In 1910 the enabling acts for the states of New Mexico and Arizona provided for reservation of lands actually or prospectively valuable for the development of water power and transmission of power, and later in the same year Congress authorized the withdrawal of lands generally for water power sites.

On February 24, 1911, Congress amended Section V of the original reclamation act, authorizing power development on all projects with power to be contracted for periods up to 10 years, except that on the Rio Grande Project authority was given for power contracts up to 50 years, and a similar authorization with respect to the length of the power contract was extended to the Salt River Project (Arizona) in the Act of September 18, 1922.

Nowhere in the Bureau legislation is power production accorded recognition as a function superior to the use of water for any other purpose. Section 8 of the Reclamation Act requires a procedure in conformity with state and territorial laws in establishing water rights as a result of which power rights have been established; and these power rights are in some cases in apparent conflict with subsequently established irrigation rights—yet the policy in power operations to date has been strictly one of noninterference with any irrigation.

Power

Although power development was not mentioned in the original reclamation act, and the transmission of power over material distances was still in its infancy in the earlier years of the twentieth century, it is noteworthy that, even before 1910, provision for future power development was made in the designs for practically every dam of real height, among these being the Shoshone (Wyoming), Arrowrock (Idaho), Elephant Butte (New Mexico), and Pathfinder (Wyoming) dams. Irrigation pumping required a power plant as at Minidoka Dam (Idaho).

All the earlier Bureau power plants were built either because they were required for irrigation pumping on Bureau projects, with their capacity wholly or largely so used, or because this power output was needed for project construction purposes. Among the first type were the Minidoka and Black Canyon plants in Idaho and the Kennewick plant in Washington. Among the second type were the Roosevelt (Arizona), Lahontan (Nevada), Boise (Idaho), Pilot Butte (Wyoming), Shoshone (Wyoming), and Lingle (Wyoming) plants, some of which, in anticipation of but a few years of operation, were not adequately planned for permanent use. Markets promptly opened up for the surplus output of all these plants.

Subsection I of the Fact Finder's Act (December 5, 1924) provided that profits from the operation of power projects be utilized in meeting the con-

struction charges of the projects on which the power is produced, with the revenues ultimately to go to the irrigators themselves. This legislation expressed the policies that had been followed previously. However, during the succeeding few years there was a growing appreciation that such a policy was leading to inequalities in irrigators' obligations as between projects that did, and projects that did not, have power plants to assist in paying for the projects, and that furthermore the irrigators' resulting interest in power rates and power revenues tended to hold power rates at unduly high levels.

Following the passage of the 1924 Fact Finder's Act, it soon became evident that, because of the changing character of power developments, and in the interest of the best utilization of power production, power developments should be segregated from irrigation. In the late 1920's and the early 1930's this segregation was accomplished in a number of instances by special laws, and finally by the general legislation of the 1939 Reclamation Project Act which in Section IX provided for allocation of construction costs to power and the return of such costs to the United States from power revenues.

By 1920 the coming importance of power was clearly recognized and long-distance transmission was accepted as wholly feasible. Hydro power production became more attractive and bureau river planning began to give due attention to the inclusion of power, with such joining of irrigation and power plans as to secure as much power ultimately as possible without material sacrifice in irrigation.

Flood Control

The projects initially selected for construction contained much public land and, on the whole, were located in areas where flood damage was relatively light (because of lack of widespread improvements) along the stream channels. Then, too, the settlement of the stream valleys was still new and there had been but little damage by floods. There was thus little incentive and no demand for flood control, as a result of which the reservoirs were designed, in the main, without provision for flood control; and the spillways were designed to pass floods with a minimum of cost.

There was one notable departure from this policy and that was on the Rio Grande Project where some 400,000 acre-ft of reservoir capacity was officially indicated to be available for flood control. The known floods of the preceding years, together with a very limited channel capacity below the reservoir, had already done much damage over the period of settlement of the valley below the reservoir—dating back fully 200 years.

Although construction of irrigation projects was started in 1904, no main stream reservoirs were completed before 1909. A considerable number was completed between 1909 and 1915. In the initial project operations the major interest of both the farmers and the project personnel was to assure a full reservoir; but it was not long until the people along the streams demanded that the constructed reservoirs be operated for flood control also, and the most vociferous among them usually had no obligation for repayment of costs.

The insistent demands for flood control operations at the important reservoirs led to developments. Agitation was begun for recognition by Congress

of the need for providing more adequately for flood control by legislation which would relieve the irrigators from paying for flood control that would not benefit them. In Congress the feeling was that the reclamation program was already providing material subsidies and that desired arrangements providing flood control would be merely a further subsidy. Concurrently, it became a practice to adjust spillway plans so as to dampen flood peaks and to increase outlet capacities below the spillway level to the greatest extent practicable without materially adding to reservoir costs, thus accomplishing a measure of flood control.

The Boulder Canyon Project Act of December 21, 1928, was the first legislation to recognize flood control as a specific function of a reservoir but it failed to authorize an allocation of cost for that purpose, instead providing for the return of the entire cost, with interest, of the reservoir and power development from water and power revenues. On July 19, 1940, Congress designated $25,000,000 of the construction cost to be considered an allocation to flood control, repayable after 1987 without interest.

The Reclamation Project Act of August 4, 1939, in Section IX, laid down a general law applicable to all future projects with provisions for suitable nonreimbursable allocations to flood control, thus extending to projects of the Bureau of Reclamation the policy that had long been in force with projects of the Corps of Engineers—of federal responsibility for flood control. Later the Central Valley Project of California with its Shasta Reservoir and the Columbia Basin Project with its Grand Coulee reservoir, authorized by special laws prior to 1939, were brought under that general 1939 law.

The 1939 general law required consultation by the Bureau with the Corps of Engineers on flood control matters and this arrangement was strengthened by the Flood Control Act of December 22, 1944.

Navigation

In its operations, the Bureau first encountered navigation in an important degree on the Central Valley Project where the operations of the Shasta Reservoir are designed to assist navigation on the Sacramento River materially. In a lesser degree Marshall Ford Dam on the Colorado River in Texas and the Grand Coulee Reservoir were recognized as affecting navigation. The Reclamation Project Act of 1939 authorized suitable nonreimbursable allocations of costs for navigation in the same way as for flood control.

In more recent years, as Bureau activities have extended from the headwaters down onto the main streams, the need for consideration of navigation has increased and the stream operating plans, as well as the justified allocations for navigation, are receiving major consideration. In such work there must of necessity be close cooperation with the Corps of Engineers.

Silt Control

Prior to the settlement of the west most stream valleys were in substantial balance between the silt-carrying capacity of the streams and the silt loads brought to them. This balance was first disturbed by overgrazing with re-

sultant increased erosion; later the disturbance was augmented by gullying along roads, railroads, and cattle trails. The southwestern streams then began building up their channels. The main stream irrigation reservoirs have deprived the streams of a goodly part of their silt-carrying capacity which rested largely in their flood flows. Irrigation of the river valleys has resulted in valuable lands and improvements, private and public, entitled to adequate flood control protection, which in turn will still further reduce the silt-carrying capacity of the stream. Some valleys which were substantially in balance before settlement are seriously endangered by rising river beds; the Middle Rio Grande Valley of New Mexico is probably one of the worst in this respect. With streams of relatively light silt loads, the impending silt menace becomes clear only as irrigation regulation enters its final stages. The North Platte Valley in Nebraska is of this type.

In a way, silt control is associated with flood control but suitable legislation giving complete recognition is needed in order that all situations requiring silt control can be assured of adequate attention without reliance on some other objective to meet the cost properly chargeable to silt control.

Fish and Wildlife

The early project plans and dam designs made no provisions for fish and wildlife. As a rule the reservoirs added measurably to the values of both—particularly so when power development assured the maintenance of adequate dead storage and thus avoided the complete drainage of reservoirs with consequent loss of fish life. Where such dead storage was not assured by power development, the justified criticism occasioned by the big loss of fish life when reservoirs were emptied soon led to the adoption of the policy with regard to design and operation that adequate pools would be retained even when the worst irrigation shortages existed. Reservoirs present major opportunities for an increase of fish and wildlife resources, but not until August 14, 1946, was legislation enacted enabling a nonreimbursable allocation of project costs for fish and wildlife benefits where such benefits exceed the damages by the same project. Aside from maintenance of dead storage pools, the initial demand by fish interests was for the fine screening of outlets. Further study resulted in discarding this requirement with deep outlets. Quite recently the Bureau has been requested in some instances to arrange for waters to be released from the surface instead of from deep outlets, to provide warmer waters and consequently better food for fish below the reservoirs. In other cases cool waters are wanted, and always there is a demand for elimination of extremely high and low discharges. More recently rearing ponds have been suggested around reservoirs to enable small fish to reach a size where they do not fall prey to the large fish and also to facilitate destruction of undesired species. Federal and state agencies are engaged in broad programs of needed studies to enable full realization of the opportunities for improvement of fishing values in reservoirs built by the Bureau of Reclamation. There is a prospect that such values, in some cases, will reach major proportions.

Recreation

The recreational possibilities of reservoirs are only now beginning to be recognized, this delay being due to lack of access roads and lack of conveniences for use by the public around the shores. There are insistent and increasing demands for public acquisition and improvement of shore lands for public use. The recreational facilities so far provided are largely the result of work by the Civilian Conservation Corps (CCC) and the Works Progress Administration (WPA) camps. The Bureau is not authorized to make expenditures for this purpose and its part in the program has been to supply such work as could be done incidental to other authorized purposes. There is urgent need for legislation which will enable direct expenditures for the acquisition of shore lands for public use and for the improvement of recreational opportunities, such expenditures to be nonreimbursable by the users of water for power in recognition of their public uses. There is also need for authority to condemn land for such purposes, as shore line owners are reluctant to part with shore lands at reasonable prices.

Summary

The Bureau of Reclamation was organized in 1902, pursuant to the Reclamation Act of 1902, with authority to construct irrigation projects. Irrigation alone was authorized by the original act. Possibly the authors of the Reclamation Act did not envision the multiple uses of reservoirs which are in effect and contemplated. The immediate need was the enactment of a law to give urgent assistance on irrigation. The Bureau took advantage of most of its opportunities in providing for power development, flood control, navigation, protection of fish, and recreational uses. As long as the entire construction costs had to be repaid by the users of water and power, expenditures for purposes other than the production of water and power of necessity had to be limited to negligible amounts. Special and general authorization was repeatedly, but often unsuccessfully, sought for adequate expenditures for other purposes; but there is always considerable opposition to nonreimbursable expenditures, and properly so. A further factor making for delays in such procedures is the relationship with other governmental agencies which have been assigned responsibilities in their respective fields, similar to those of the Bureau in the field of irrigation and power. The bureau recognizes the need for comprehensive multiple-use planning on any and all reservoirs yet to be built, and for adjustment in the operation of existing reservoirs to accomplish all purposes in so far as that may be attained without injury to vested rights. The accomplishment of these ends will require additional authorizing legislation and, where the circumstances so justify, nonreimbursable appropriations to the end that purchasers of water and power will not be required to pay for services provided for the general public.

GENERAL PROBLEMS OF DESIGN AND OPERATION

By Nicholls W. Bowden,[4] M. ASCE

Beginning about 1928, the increasing recognition by the engineering profession of the advantages of multiple-purpose dam and reservoir projects for river control—particularly for irrigation, flood control, navigation, and power uses—resulted in the construction of many such structures in the United States and the proposed construction of many more in the near future. It is scarcely necessary to substantiate this statement in the light of projects completed during the period such as: (1) The Sacandaga Reservoir in the Hudson River Basin, a pioneer multiple-purpose project; (2) the development on the Colorado River consisting of Hoover, Parker, Imperial, and Davis dams built or building; (3) Grand Coulee and Bonneville dams on the Columbia River in Washington and Oregon; (4) the Central Valley Project in California; (5) the dams in the Allegheny and Monongahela rivers above Pittsburgh, Pa.; and (6) the Tennessee River system of multiple-purpose dams and reservoirs, shown in Fig. 1.

Previously (mostly since the turn of the century), the rivers of the United States had been developed for single purposes, in whole or in part by public funds, for navigation, irrigation, and flood control; and by private capital, for power. Some of these improvements involved large dam and reservoir projects.

The rapid shift to multiple-purpose projects presents a challenge to civil engineers in the planning, or general design, of the projects and, even more, in their operation. This is a new field of applied hydraulics, one largely unexplored and uncharted, and the engineer engaged in this field has had to depend largely on his own ingenuity in planning and in operating these projects. He should remedy this situation as soon as possible by giving to the profession the benefit of his experience. The planning of such reservoirs is so closely related to the operation that the two should not be separated. Because the size of a reservoir will more or less determine how it must be operated, the proposed method of operation should be critically considered during the planning stage. The primary operating purpose also should be clearly defined.

Multiple-purpose reservoirs should generally be larger than single-purpose reservoirs, how much larger depending on the uses to be served and economic considerations. The ideal size, often unattainable because of excessive flowage costs or topography, would afford ample allocation of storage space for each purpose. Ample storage space under one method of operation may be quite different from that under another. For example, the space required for flood control would be much larger if the operating method provided for storing all inflow during a flood or during a season instead of discharging part of that inflow. Also, in a large river basin where reservoir control obtains on all the principal tributaries, as well as on the main stream, thus affording the oppor-

[4] Head Hydr. Engr.; Chf., River Contro lBranch, TVA, Knoxville, Tenn

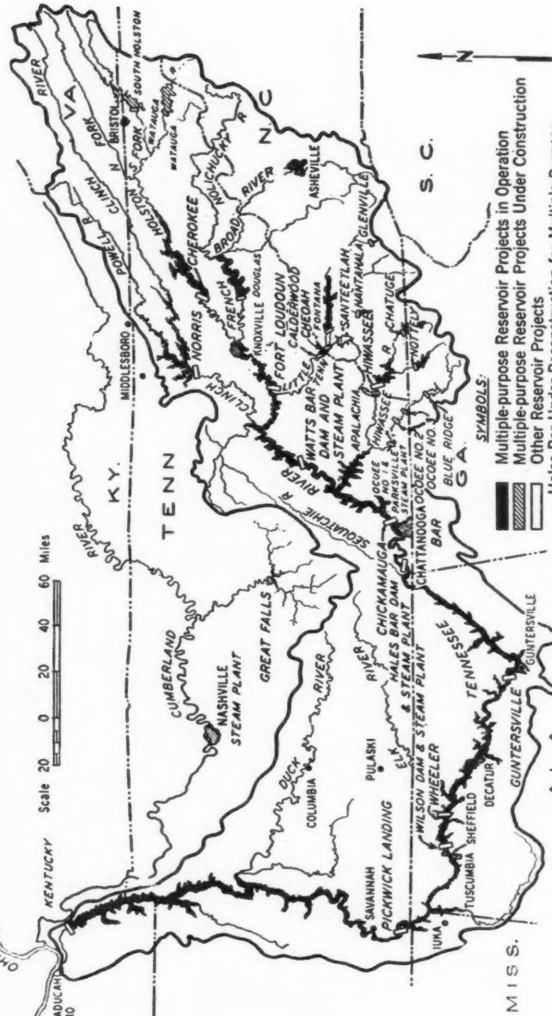


FIG. 1.—THE TENNESSEE RIVER SYSTEM AS OF 1946

tunity for reregulating flows, the allocation of storage space for the several purposes may vary from that for single reservoirs or that for a less completely controlled basin.

These conditions do not signify that the sound principle of constructing reservoirs of adequate size should be abandoned; but instead that, under certain conditions, reservoirs of smaller size may be used effectively, as has already been demonstrated in practice. It is fortunate that smaller reservoirs are practicable, since, because of the development of river valleys with industries, transportation lines, etc., and sometimes because of topographic limitations, sites for large reservoirs are often nonexistent. A striking illustration of this condition is offered by the Allegheny and Monongahela river basins, where a system of reservoirs is being built for the purpose, among others, of regulating floods in the Pittsburgh section under considerable restrictions in flood storage possibilities. In this connection, Emil P. Schuleen,[5] Assoc. M. ASCE, has presented a table showing the inches of runoff control afforded by the existing and proposed reservoirs. If the engineers had insisted on greater control of runoff in the drainage areas of those reservoirs, the much needed regulation of floods in this important region (where one flood alone, in 1936, caused damages estimated to exceed $175,000,000) might not have been realized.

Since the principles involved in planning and operating reservoirs for power are well known, as are those pertaining to navigation improvements, this paper will deal mostly with the flood control features of multiple-purpose reservoirs, about which too little is known. Various criteria have been advanced as desirable for the size of reservoirs for flood control. Perhaps more applicable to the humid eastern section of the United States, they range from half the average annual runoff to 8 in., or somewhat less, and offer to the engineer a wide range within which to study the characteristics of his own particular problem, and on which to base his plans. Wherever feasible, reservoirs may be planned in accordance with these desirable requirements with great assurance of success. Some of the existing multiple-purpose reservoirs that meet the foregoing specifications are: Lake Mead (Arizona-Nevada), planned to store about 80% of the average annual runoff; Sacandaga Reservoir (Hudson River Basin), whose capacity is nearly 14 in. of runoff; and Norris, Fontana, Hiwassee, Chatuge, and Nottely reservoirs (Tennessee Basin), which have a storage capacity of about 10 in. of runoff at the beginning of the flood season on January 1, about 8 in. on March 15, and about 6 in. on April 1, near the end of the major, valley-wide flood season. Because it is often impracticable to locate reservoir sites that afford such good control of runoff, the engineer must either forego using reservoirs or be satisfied with less control. The latter will be his decision if he can devise operating methods adequate to meet the situation; and, thus, in a major sense, planning merges with operation.

What then should be the criterion for planning the size of such reservoirs? The writer is unable to give a specific answer, as that must come from a study of each situation, but hopes that the suggestions in this paper will be helpful. Personally, he believes that, when it becomes necessary in the future, engineers

[5] "Control of Floods at Pittsburgh Planned," by Emil P. Schuleen, *Civil Engineering*, October, 1945, p. 454.

will find it feasible to reduce reservoir storage requirements considerably. The extent of control deemed essential will undoubtedly depend largely on operating methods to be followed, improved operating technique, and the reliability of precipitation predictions. It will also depend on weather characteristics and other features peculiar to the region.

In the eastern United States, where, over large basins, precipitation averages, say, from 40 in. to 55 in. annually and a great flood producing storm may yield 20% of that amount, reservoirs capable of controlling 8 in. of runoff should be adequate. Reservoirs with less control can be operated (although it is more difficult) to save storage space for only a relatively short time at the crest of the flood, after which they can be drawn quickly to flood control level by spillage. This procedure is necessary for the main stream reservoirs on the Tennessee River, although in lesser degree for Kentucky Reservoir (see Fig. 1).

The guide curve governing the multiple-purpose operation of Douglas Reservoir, which does not have a high degree of runoff control in relation to the drainage area of 4,541 sq miles, and the actual operation of the reservoir in 1946 are shown in Fig. 2(*a*). The maintenance of multiple-purpose features is assured through the prompt restoration of required flood storage space by spilling water stored during the January flood (which, without regulation, would have been the fifth largest of record at Chattanooga, Tenn.) and also during the February flood. The deficiency in desirable filling of the reservoir after the end of the flood season in April would not have resulted if encroachment on flood storage space had been permitted by holding in storage some of the water from the January and February floods.

Where flood control and power are combined in the same reservoir, with or without other uses (not an infrequent condition), perhaps more uncertainty exists as to the feasibility of successful operation for flood control than in any other combination of uses. Experience with the Tennessee River system of reservoirs indicates that, with proper operation, there is no need for such uncertainty. Moreover, the increasing number of reservoirs throughout the United States combining these two purposes shows a growing confidence in their effectiveness. In such reservoirs, the superimposed storage space assigned to flood control should be adequate to control, properly, the runoff from the contributing drainage area under the plan of operation contemplated. The multiple-purpose reservoir will be just as efficacious for flood control as a single-purpose reservoir containing the same volume of flood storage space, provided that encroachment on the space reserved for flood control is not permitted in operation. In a properly planned multiple-purpose reservoir, particularly in a well integrated system having good interconnections and suitable capacity of stand-by power, the energy gained by keeping the reservoir full is of questionable temporary value, as it may be lost later by spillage.

The Tennessee River system of multiple-purpose reservoirs will be used largely as the subject for further discussion, as the writer is most familiar with that system. Clarence E. Blee,[6] M. ASCE, has presented a most complete

[6] "Multiple-Purpose Reservoir Operation of Tennessee River System," by Clarence E. Blee, *Civil Engineering*, May, 1945, p. 219, and June, 1945, p. 263.

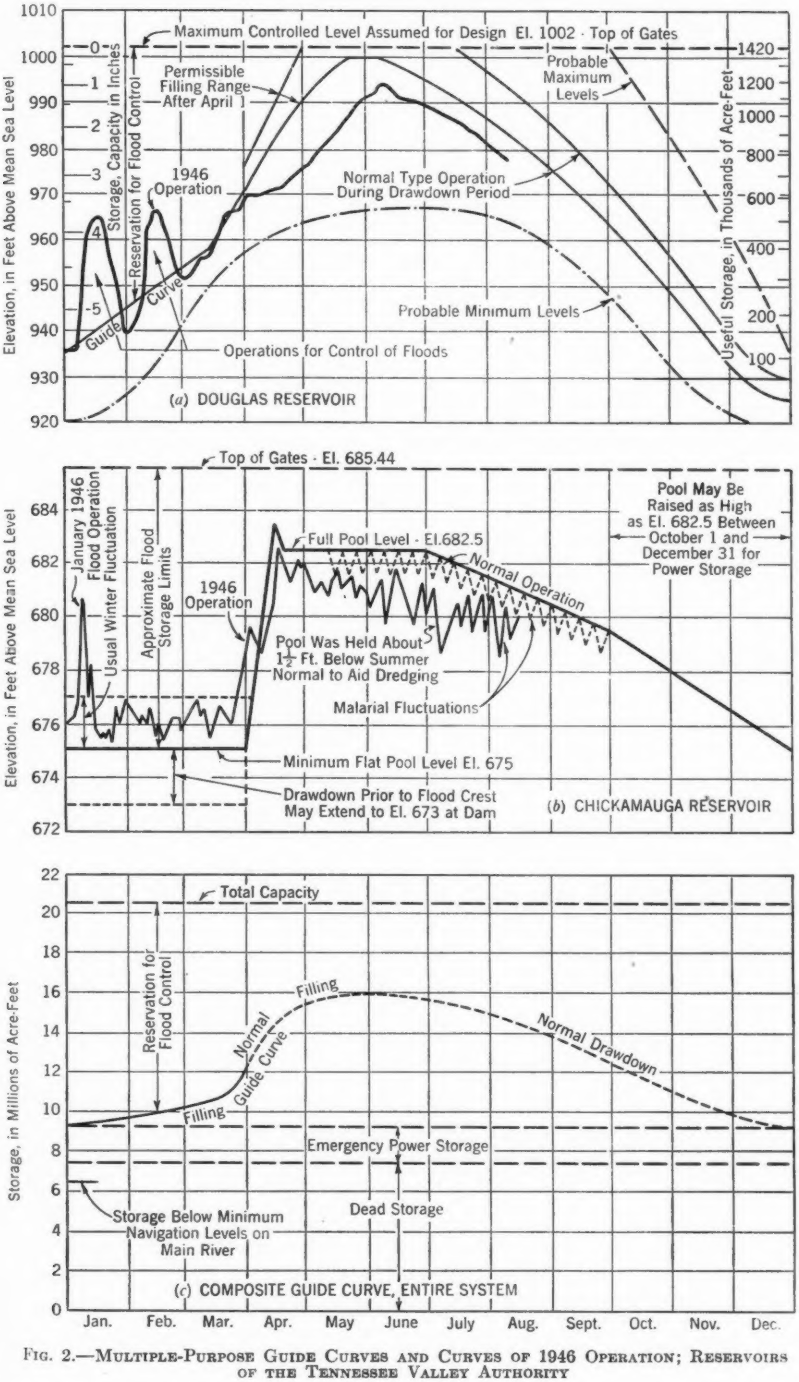


FIG. 2.—MULTIPLE-PURPOSE GUIDE CURVES AND CURVES OF 1946 OPERATION; RESERVOIRS OF THE TENNESSEE VALLEY AUTHORITY

exposition of this system. Including the five single-purpose power projects of the Aluminum Company of America on the Little Tennessee River (the operation of which is controlled by the TVA under an agreement between the two parties) and the single-purpose power projects acquired some years ago by TVA from the Tennessee Electric Power Company, there are twenty-six projects in the Tennessee Basin and one on Caney Fork River in the Cumberland River Basin. Of these, fifteen are multiple-purpose reservoir projects, some important features of which are shown in Table 1 and in Fig. 2(*c*).

TABLE 1.—MULTIPLE-PURPOSE R

No.	Reservoir	River	Local drainage area[a] (sq miles)	FLOOD STOR: JANUARY 1: El.	Storage (acre-ft)	Runoff control (in.)
1	Kentucky	Tennessee	7,380	354–375	4,010,800	10.2
2	Pickwick	Tennessee	2,070	408–418	418,400	3.8
3	Wilson	Tennessee	1,160	504.5–507.9	52,500	0.8
4	Wheeler	Tennessee	5,140	550–556.3	348,900	1.3
5	Guntersville	Tennessee	3,660	593–595.4	162,900	0.8
6	Chickamauga	Tennessee	2,512	675–685.4	329,400	2.5
7	Watts Bar	Tennessee	3,277	735–745	377,600	2.2
8	Fort Loudoun	Tennessee	1,580	807–815	109,300	1.3
9	Cherokee	Holston	3,429	1,020–1,075	1,145,900	6.3
10	Douglas	French Broad	4,541	935–1,002	1,311,200	5.4
11	Norris	Clinch	2,912	978–1,034	1,635,000	10.5
12	Fontana	Little Tennessee	1,571	1,615–1,710	771,160	9.2[c]
13	Hiwassee	Hiwassee	565	1,455–1,526.5	291,100	9.7
14	Chatuge	Hiwassee	189	1,910–1,928	105,400	10.4
15	Nottely	Nottely	214	1,743–1,780	110,050	9.7
16	Total	....	....	....	11,179,610	....

[a] Below next upstream dam in case of Tennessee River reservoirs and Hiwassee reservoir. [b] Could use st and Glenville areas.

The basin has an average annual precipitation of about 52 in., from which the runoff is about 23 in. Although the precipitation is fairly well distributed throughout the year (the monthly average varying from about 3 in. in the fall months to about 5 in. during the first 3 months in the year), natural runoff is much greater in the winter and early spring. During January, February, and March, it amounts to approximately 10 in. at Chattanooga, or nearly half the annual runoff. In wet years, it is relatively higher. This high runoff is accounted for by the heavy storms, usually several days in duration, which occur during the flood season, and by the high percentage of surface runoff caused by dormant vegetation. Subsequently, from April to October, inclusive, the runoff decreases steadily, to less than 1 in. in the latter month, before recovering slightly in the last 2 months of the year.

The annual cyclical method of operating reservoirs indicated in Figs. 2(*a*) and 2(*b*) (which are typical for tributary and main stream reservoirs, respectively) is designed to fit this stream flow pattern. In general, these guide curves provide for gradually filling tributary reservoirs during the first 4 or 5 months of the year, for maintaining water near its highest level for 2 or 3 months in the summer, and for gradually drawing the level down during late summer

and fall to minimum flood control level by January 1 to complete the annual cycle. Somewhat similarly, main stream reservoirs are held at minimum flood control level, except during flood control operations, from January 1 until about April 1, then filled to pool-full level by about April 15, held at that level until July 1, and finally gradually drawn down to minimum flood control level by January 1. Although reservoirs are at high level for 2 or 3 months, storage space is still available, as shown in Table 1 and Fig. 2(*c*), for regulating such flash floods as may occur in that season.

ERVOIRS, TENNESSEE RIVER SYSTEM

AGE SPACE			STORAGE SPACE AVAILABLE DURING SUMMER PERIOD			No.
MARCH 15						
El.	Storage (acre-ft)	Runoff control (in.)	El.	Storage (acre-ft)	Runoff control (in.)	
354-375	4,010,800	10.2	359-365[b]	1,044,200[b]	2.7	1
408-418	418,400	3.8	414-418	179,200	1.6	2
504.5-507.9	52,500	0.8	....	....	....	3
550-556.3	348,900	1.3	556-556.3	20,800	0.1	4
593-595.4	162,900	0.8	595-595.4	31,200	0.2	5
675-685.4	329,400	2.5	682.5-685.4	108,500	0.8	6
735-745	377,600	2.2	741-745	163,500	0.9	7
807-815	109,300	1.3	813-815	29,990	0.4	8
1,042-1,075	807,200	4.4	1,073-1,075	61,400	0.3	9
958-1,002	1,019,800	4.2	1,000-1,002	62,100	0.3	10
990-1,034	1,377,000	8.9	1,020-1,034	520,000	3.3	11
1,644-1,710	581,770	6.9[c]	1,708-1,710	21,180	0.3[c]	12
1,472-1,526.5	245,100	8.1	1,524.5-1,526.5	12,400	0.4	13
1,916-1,928	75,100	7.4	1,926-1,928	13,980	1.4	14
1,755-1,780	83,500	7.3	1,778-1,780	8,420	0.7	15
....	9,999,270	....	....	2,276,870	....	16

age space up to El. 375 if necessary (3,290,000 acre-ft). [c] On total area above Fontana, including Nantahala

The foregoing plan not only conforms to stream flow characteristics but also affords optimum benefits to the statutory purposes of navigation, flood control, and power production, and, in so far as consistent with those major uses, serves other useful purposes. Quite important among such other purposes, because the public health is involved, are operations for malaria control conducted on main stream reservoirs, as shown in Fig. 2(*b*). They include a 1-ft surcharge in April to strand flotage and a weekly, cyclical fluctuation about 1 ft deep between May 15 and October 1, combined with several feet of recession in pool level between July 1 and October 1. These operations and other water level management operations, such as the gradual drawdown of Kentucky Reservoir and tributary reservoirs during the mosquito breeding season, are effective in maintaining a clean shore line and in stranding and helping to destroy the larvae of the malaria-carrying mosquito.

Other incidental although important purposes served are (1) recreation, secured by maintaining suitable water levels and discharges, when practicable, for the propagation of fish during the spawning period and for such sports as boating and fishing; (2) sanitation and water supply, by making special discharges when needed; and (3) numerous others such as refloating stranded

boats and ferries and aiding farmers in fording or ferrying to tend or harvest crops on islands, accomplished also by making special discharges.

The navigation purpose of providing for a minimum 9-ft draft in the main river is obtained by nine dams and locks, supplemented by dredging in the upper end of the pools. By regulating flows throughout the year, the pools are held at levels which provide the required or greater depth. Minimum pool level for this purpose is also the minimum allowable for power. The reduction of flood flows in the pools, through the operation of the system, is helpful to power by maintaining greater main river heads, and to navigation by reducing current velocities and increasing headroom under bridges. The storage of water permitted by the gradually rising guide curve in the winter and the spring flood season for controlling floods benefits both power and navigation through its later use in the low-flow season. Likewise, the low-flow season draft of this water from reservoirs in advance of the flood season benefits flood control by providing storage space for that purpose. This regulation has increased the minimum daily flow at the mouth of the river from less then 10,000 cu ft per sec to about 25,000 cu ft per sec. Gerard H. Matthes,[7] Hon. M. ASCE, chairman of the ASCE Joint Division Committee on Floods, in his 1943 Progress Report on "Floods," stated, in part:

> "* * * Two additional reservoirs, the Kentucky Reservoir near the mouth of the river and the Fontana Reservoir on the Little Tennessee River, with prospective storage capacities of 4,600,000 acre-ft and 1,200,000 acre-ft, respectively, are nearing completion and will make the Tennessee River and its tributaries the most perfectly regulated river system of its size in the world. * * *"

It must be remembered, in appraising the results of the first decade of operations of the TVA system, that many vicissitudes were encountered not hereafter to be expected, including: (1) The pioneering nature of multiple-purpose operations; (2) the frequent need of abnormal flow regulation, usually unsuited to best multiple-purpose results, to protect construction work in progress; (3) the temporary operation of several reservoirs during the World War II emergency primarily for power; (4) the greatest flood of record on the Mississippi River at Cairo, Ill., in 1937, when the system was too small to have much effect; and (5) the record-breaking dry period in 1939–1941 at a time of rapidly increasing power load. These factors imposed a severe load on the system, and on those responsible for its operation, while it was growing and changing and consequently less susceptible of efficient operation.

Storms severe enough to cause basin-wide floods usually travel across the Tennessee Basin in a northeasterly direction, causing heavy precipitation and increased runoff in the western section some 12 hr to 24 hr earlier than in the eastern section. This meteorological characteristic is a favorable one, because it permits the initiation of regulatory measures progressively upstream in the main river and the discharge of runoff from lower river areas ahead of upstream peaks. Quantitative predictions of precipitation, from 36 hr to 48 hr in advance, are furnished for seven basin subdivisions three times daily, and the general weather outlook up to 5 days ahead is supplied once daily by the United

[7] *Proceedings*, ASCE, February, 1944, p. 176.

States Weather Bureau during the flood season under a cooperative arrangement initiated in 1939. These data are of inestimable value in day-to-day (and sometimes even more frequent) adjustment of discharges throughout the system. Although rainfall cannot yet be forecast with great accuracy, much improvement has been made in recent years, particularly under the stimulus of World War II. Without help of this nature, multiple-purpose reservoir operation would suffer a severe handicap.

Under natural flow conditions, peak flood discharges from the Tennessee River ordinarily reach the confluence of the Ohio and Mississippi rivers at Cairo in advance of the peaks from those two rivers. The continuous main river dam system on the Tennessee River makes it feasible to accelerate greatly the movement downstream, and offers the opportunity of passing the Tennessee peak into the Ohio and Mississippi rivers still farther ahead of the crest from those rivers. In the large flood of January, 1946, the acceleration amounted to about 5 days, as indicated in Fig. 3(*a*). Thus, space is available in the reservoirs for storing during the crest period at Cairo or Paducah, Ky., the control points, if the flood reaches dangerous proportions. In the event of successive crests, such as those in March and April, 1945, when a triple crest flood occurred which would have reached rather threatening stages ranging from 54.5 to 55.6 at Cairo, reservoir operations become a sustained effort of timing discharges to effect crest reductions, if stages are high enough to warrant this action. Fig. 3(*b*) shows the regulation of the three crests at Cairo and one at Paducah, the reductions at the former city varying from 0.7 ft to 1.7 ft, the largest reduction being from the highest crest, and 2 ft at the latter city. Because of construction operations, storage space in Kentucky Reservoir was not available for use in these operations except to a very limited degree.

In 1937, when the highest flood of record at Cairo occurred, the stage reached 59.5 ft on February 3, about a week after the New Madrid (Mo.) Floodway was opened at around stage 58. Cairo was seriously threatened, mud boxes placed on top of levees being nearly overtopped. At that time only Norris, Wheeler, and Wilson reservoirs were available, and the storage space of the latter was too small to be of consequence. Computations made subsequent to the flood indicated that a reduction of from 0.3 ft to 0.5 ft was effected. Although it was small, that regulation under the circumstances may have been of great importance.

Since that flood much raising and strengthening of levees has been done by The United States Engineers and probably a flood as great or greater now could safely be carried at and below Cairo. Protection works at Paducah will have a top elevation about 3 ft higher than the flood crest in 1937. It would seem, then, that henceforth no stage of less than, say, 55 at Cairo or Paducah should be considered dangerous and worthy of regulation. If higher stages are predicted, regulation should be based on the predicted crest, or on an even higher one in case of subsequent rainfall sufficient to affect the crest. The foregoing suggestion applies to the major flood season. In the summer, when damages to crops may accrue between the levees and in backwater areas, it may be found desirable to regulate floods reaching flood stage (40 ft) at Cairo.

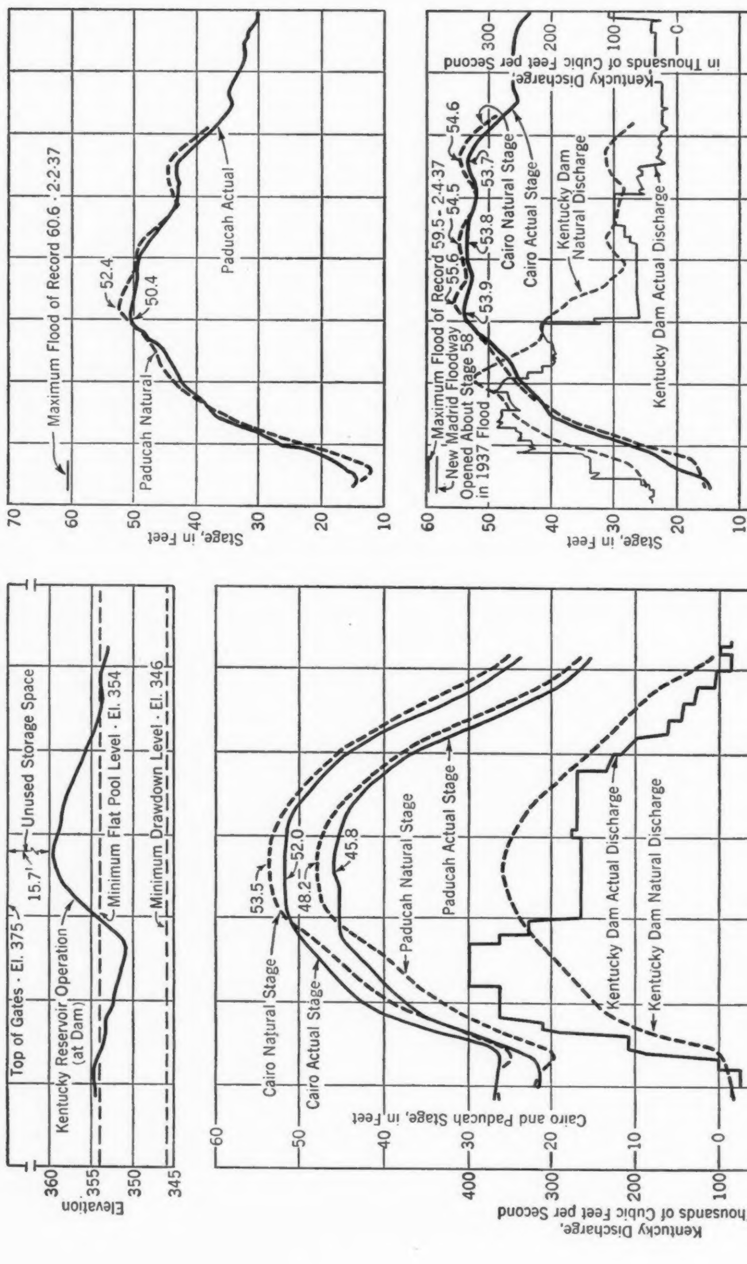


FIG. 3.—REGULATION OF FLOOD CRESTS AT PADUCAH, KY., AND CAIRO, ILL., BY TVA RESERVOIR SYSTEM

To control the contribution from the Tennessee to the Ohio and Mississippi rivers, so as to be most beneficial, frequent contact has been maintained during floods with the U. S. Engineer offices in charge of those rivers, as well as with the U. S. Weather Bureau at Cairo. Weather and river conditions and predictions obtained from these sources have made it possible to follow the course of floods down those rivers and to operate the Tennessee River reservoir system accordingly. Under Section 7 of the Flood Control Act of December 22, 1944, the TVA is directed to regulate the release of water from the Tennessee River into the Ohio River in accordance with such instructions as may be issued by the War Department in case of danger from floods on the lower Ohio and Mississippi rivers. This directive serves the purpose of integrating the flood control operations of the TVA system with those on the Ohio and Mississippi rivers under the control of the U. S. Engineers.

The 1946 flood season afforded the first opportunity for this new plan to function. Methods previously developed and put into effect for exchanging data provide that when the Cairo stage is 35 ft, with 40 ft or higher predicted, the TVA shall report by teletype, early each day, the observed data for main river reservoirs from Chickamauga to Kentucky dams, inclusive, giving rainfall, stages, and discharges. Later each day predicted schedules of stages and discharges from 3 days to 5 days in advance are reported. The Ohio River Division Office of the U. S. Engineers at Cincinnati (formerly at Columbus), Ohio, and the Upper Mississippi River Division Office at St. Louis, Mo., reciprocate by similarly furnishing the TVA observed data and predicted discharges at a number of key points on the Ohio and Upper Mississippi rivers and on certain tributaries. In addition, when the Cairo stage is 50 ft or higher, the Mississippi River Commission, at Vicksburg, Miss., furnishes the TVA daily with current stages and predicted stages on the Mississippi River from Cairo to New Orleans, La., 7 days in advance, together with predictions of date and height of crest at all stations.

The foregoing procedure was followed throughout the January, 1946, flood. This flood was the eighth highest of record in the lower Tennessee Valley but was of rather moderate height at Cairo and Paducah, where computed natural crest stages of 53.5 and 48.2, respectively, were reduced to 52.0 and 45.8 by reservoir action, as shown in Fig. 3(*a*). Since dangerously high stages were not reached or in prospect, the U. S. Engineers did not issue any instructions as to the regulation of releases from the Tennessee River into the Ohio River. In Fig. 3(*a*), it may be noted that:

(1) The modified hydrographs at Cairo and Paducah have exceptionally smooth, flat crests;

(2) A little more than 3 ft of the permissible 8-ft drawdown at the lower end of Kentucky Reservoir was effected in seeking to maintain constant volume in that reservoir before the flood peak arrived and in speeding the movement of the Tennessee peak at Kentucky Dam into the Ohio and Mississippi rivers ahead of the crests there; and

(3) The lower end of the reservoir was filled only to about El. 359, thus conserving storage space for use in case the flood should subsequently develop into one of dangerous height.

The method used at Kentucky Dam is a good example of reservoir operation planned in advance, as the result of several years of study. If the Kentucky Reservoir had been operated to obtain maximum effect, the Cairo and Paducah crests could have been reduced about 6 ft.

Because of the reservoir's large size (capacity equivalent to more than 10 in. of runoff on its local drainage area of 7,380 sq miles) and its strategic location (22 miles from the Ohio River and 67 miles from the Mississippi River, only about a day away in time of water travel), it serves admirably for reregulating discharges from the entire system of upriver reservoirs and for fixing and timing the output of water from the Tennessee River.

Although the method of operating the other main stream reservoirs is basically similar to that at Kentucky Dam, it is absolutely essential, because of their smaller size, to conserve as much as possible of their flood storage space for occupancy during a comparatively short period of flood crest regulation, if the reservoirs are to be effectual. Thus, delicate timing is required, usually complicated by weather changes and the necessity for prompt and accurate runoff computations and stream flow routings, both current and prospective.

By withholding water in tributary reservoirs until the peak from the main river contributory drainage has passed Chattanooga (as is the usual procedure, and as was done in the major flood of January, 1946, the fifth highest of record at Chattanooga in about 75 years), the burden on the main stream reservoirs is lightened. To accomplish this control, tributary reservoirs must be operated in coordination with main stream reservoirs, in both of which the required flood storage space must be held in reserve during the entire flood season except when used for regulating floods. Thus, operations during the late summer and fall drawdown period, as well as during the flood season, have an important bearing on subsequent flood control. The fall of 1945 was wet and, in order to provide the flood storage space required by the end of the year, a total of more than 1,000,000 acre-ft of water in excess of turbine requirements was spilled, in December, from the five major tributary reservoirs and through main stream reservoirs, augmented by additional spill from the latter.

During a great flood, such as those of 1867 and 1886, or some still larger possible flood, rather large releases from tributary reservoirs will be necessary. Nevertheless, a proper appraisal of the situation, promptly made, will permit maintaining smaller outflow than inflow from these reservoirs, so regulated as to effect a material crest reduction at Chattanooga, the key control point on the Tennessee River. However, because of the low elevations of important sections of that city, complete protection cannot be provided without supplemental levees. Usually, tributary contribution to the Chattanooga peak can be limited to bank-full stage on the several tributaries, or even less. In the January, 1946, flood, tributary discharge was limited to turbine discharges, varying from about 4,000 cu ft per sec to 7,000 cu ft per sec, until the peak passed Chattanooga, and thereafter to tributary bank-full stage, amounting in each tributary to 20,000 cu ft per sec or less. These discharges were timed to flatten the receding hydrograph at Chattanooga at around the flood stage where little or no damage occurs (see Fig. 4). In contrast to these discharges, peak inflows into the tributary reservoirs varied from about 15,000 cu ft per

sec in the drainage above Hiwassee Dam to about 90,000 cu ft per sec in Douglas Reservoir.

This operation of the tributary reservoirs, together with the reregulation of flows in the three main stream reservoirs above Chattanooga, resulted in reducing not only the peak flow at Chattanooga from 320,000 cu ft per sec to 225,000 cu ft per sec and the peak stage from 45.8 ft to 35.7 ft, as shown in Fig. 4, but also the floods on the tributary streams below the dams to from 20% to 50% of their natural peak rates. The estimated savings in flood damages at Chattanooga were almost $10,000,000.

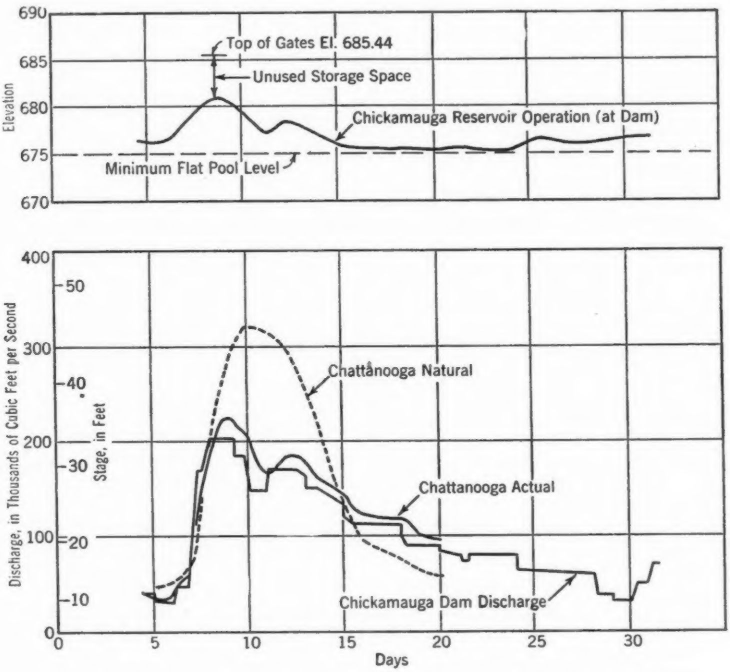


FIG. 4.—REGULATION OF JANUARY, 1946, FLOOD AT CHATTANOOGA, TENN., BY TVA RESERVOIR SYSTEM

In flood control operations of this kind, it is essential that a key point, or points, be selected as the objectives toward which such operations will be directed, as, for example, Chattanooga on the Tennessee River and Cairo on the Mississippi River in the case of the TVA system of reservoirs. Usually the objective is perfectly clear since its protection is the purpose for which the reservoir or reservoirs were built. In any event, where a big system of reservoirs is to be operated, such as that above Pittsburgh or that in the Tennessee Valley, selections should be made and operations planned accordingly. Control designed either for near-by objectives or for distant points may not always be dependable for the latter, because of the possible effect of flood runoff from other uncontrolled areas on the flood crest downstream, although such control should prove beneficial in the long term.

Handling the system of multiple-purpose reservoirs in the Tennessee Valley requires constant attention and at least daily scheduling of flows throughout the entire system for several days ahead. During floods, schedules must sometimes be revised two or three times daily to take into account changes in rainfall and runoff as they occur and effect flows and stages, with due regard for weather predictions, which are available three times daily. This scheduling is accomplished through centralized control under the chief engineer and the issuance of instructions as often an necessary to the Department of Power Operations, which is responsible for seeing that the required discharges are made at all the dams. At the central office, hydrologic data are received, assembled, and interpreted; runoff is estimated; flows are routed; and operations are decided upon by engineers thoroughly familiar with the characteristics of the system. Frequent reports received by teletype and telephone from the Operating Department at Chattanooga furnish checks on operations at the dams, and their effect on the reservoirs. Since decisions in time of flood must be made and put into effect promptly to be successful, this centralized control takes cognizance of the fact that no two storms, or the floods they produce, are alike and that each situation requires detailed treatment all its own, based, of course, on fundamental principles and procedures governing system operations. That success has been achieved under this method of control is evident from the aforementioned results. As to consistency, since the first reservoir (Norris) became available above Chattanooga in March, 1936, fourteen floods (which in their natural state would have reached or exceeded flood stage of 30 ft and caused varying amounts of damage) have occurred. The crests of all have been reduced, by amounts varying from less than 1 ft to more than 10 ft, with a total saving in damages at that point of well above $12,000,000. As of December, 1948, the number of floods reduced at Chattanooga had increased to seventeen and the total estimated savings in damages at that point to more than $40,000,000, based on estimated property values at the time of each flood.

Summary

This paper being of limited length is inadequate to cover such an important subject. If it has not always seemed to present the conventional view (which is certainly easier and usually more popular), no apology is made. The unconventional of today may be commonplace tomorrow. Whatever the reaction, it is sincerely hoped that the paper may at least stimulate thought and study and thus be helpful in the planning and the operation of the great number of large reservoir projects being built and certain to be built soon, in the United States. In the interest of clarity, the following summary of the more important contents and of some of the writer's views is presented:

(1) Multiple-purpose reservoir design and operation are real and practical and are being successfully accomplished in several major drainage basins in the United States.

(2) In planning reservoirs for flood control, whether single purpose or multiple purpose, wherever practicable, and consistent with costs and benefits, large storage space should be provided for flood control (as much as half or

more of the average annual runoff on the drainage area); but, if economic or other considerations prevent, smaller space, providing 8 in. of runoff or even less, may be ample in certain locations under appropriate operating methods.

(3) A given volume of flood control storage space should be equally as effective in a multiple-purpose reservoir as in a single-purpose reservoir, if strict adherence is given to operating rules, and encroachment on flood space is not permitted. There is no more justification for intentionally "overloading" a reservoir than for overloading any other engineering structure. Careful, intelligent, honest operation will avoid this.

(4) If encroachment on flood space is allowed, the multiple-purpose reservoir, instead of being a beneficial instrument, becomes a serious threat of flood disaster. The primary purpose should be unmistakably fixed in advance, both for the safety of the project and for the guidance of those charged with its operation.

(5) Since a reservoir or system of reservoirs cannot be operated with complete assurance of results for distant points downstream, it is usually desirable to select and to operate for relatively near-by key points and rely on benefits accruing over a period of time at greater distances.

(6) Much has been gained and much more can yet be gained in operating reservoirs by the help of quantitative predictions of precipitation.

(7) Being a highly specialized activity, often requiring prompt decisions and quick execution, the control of water in multiple-purpose reservoirs, particularly in systems, should be entrusted only to engineers who are competent and resourceful and in whom confidence, authority, and responsibility can be placed.

THEIR USE FOR FLOOD CONTROL

By Albert L. Cochran,[8] M. ASCE

Introduction

The subject of this paper raises the question: "How does the use of a 'multiple-purpose' reservoir for flood control differ from the use of any reservoir for that purpose?" It is apparent that there is very little difference, except in so far as reconciliation of the multiple interests is involved. In any case, the function of flood control storage is to impound water during periods of excess runoff in order that it may be released at nondamaging rates later. However, in certain river basins, meteorological and topographic influences limit major floods to well-defined seasons, or at least establish very consistent trends in flood magnitudes by seasons. Accordingly, part of the maximum flood control capacity may be "loaned" for other uses during the seasons of lower flood runoff.

Flood control capacity in a multiple-purpose reservoir includes only the volume that is specifically reserved for storage of floodwaters under undisputed jurisdiction of the flood control operator. Some of the flood control capacity may be utilized for other purposes during certain seasons of the year, but only at the discretion of the flood control operator. Storage of floodwaters to refill reservoir capacity allocated to some purpose other than flood control, after drawdown attending normal operation, may result in incidental flood control benefit, but such storage is not classified as "flood control," inasmuch as its availability when floods occur cannot be relied on.

Multiple-purpose reservoirs involving flood control may be placed in two principal groups:

(*a*) Reservoirs with constant allocations of storage capacity for flood control, irrespective of season of year; and

(*b*) Reservoirs with seasonal variations in flood control capacities (that is, reservoirs in which the storage capacity assigned to flood control is varied in accordance with seasonal trends in flood runoff volumes in the river basin involved).

Multiple-Purpose Reservoirs with Constant Allocations of Flood Control Capacity

In many cases, floods capable of filling all available flood control capacity in a particular reservoir may be expected with a reasonable frequency during all seasons of the year. Accordingly, seasonal use of any part of the flood control capacity for other purposes cannot be permitted without loss of flood protection. Flood control capacity is incorporated in this class of multiple-purpose reservoirs either because such provision is more economical than construction of a separate flood control reservoir of comparable effectiveness, or because construction of a separate flood control reservoir is impracticable

[8] Hydr. Engr., Chf. of Hydrology and Hydraulics Branch, Eng. Div., Civ. Works, Chf. of Engrs., Washington, D. C.

under prevailing circumstances. Operation of the flood control capacity in these reservoirs is essentially the same as that in straight flood control reservoirs.

Multiple-Purpose Reservoirs with Seasonal Variations in Flood Control Capacities

Two important objectives govern the operation of reservoirs in which the flood control capacity is varied by seasons:

(1) Sufficient capacity should be available in the reservoir on all dates to provide effective control of floods that might reasonably be expected to occur on those dates; and

(2) The reservoir storage should reach the highest level consistent with objective (1) by the end of the primary flood season, in order to provide as much water as possible for other functional uses of the reservoir—that is, the operator must strive to have just enough flood control capacity at all times, without wasting water needed for other purposes.

The best examples of this type of reservoir are found in the northwestern United States where maximum floods in large drainage basins are confined rather definitely to the winter and spring months. In that region, the greatest floods from rainfall generally precede the maximum snow-melt season. Accordingly, adequate reservoir capacity can be reserved for flood control during the winter, with the assurance that the part of the capacity not required for summer floods can be refilled during the spring snow-melt season to provide additional water for irrigation, power development, or other purposes during the summer and fall months.

In river basins in which snow melt is a consistent source of flood runoff, it is feasible to estimate approximately the volume of runoff to be expected from snow melt and incidental rainfall during the spring flood season from information regarding the water content and the extent of the snow cover within the watershed at the beginning of the melting season, with corrections and adjustments at appropriate intervals (usually monthly) during the season. In such cases, a fixed minimum storage capacity is usually reserved for control of floods that might reasonably be expected from above-normal rainfall, and the capacity between this minimum reserve and the maximum flood control capacity is varied in accordance with estimates of probable runoff from snow melt, combined with normal seasonal rainfall. Forecasts of probable runoff a month or more in advance are based, preferably, on information obtained from comprehensive snow surveys and analyses (in which checks of the water content, areal distribution, and conditions of the snow cover are made), correlated with records of observed runoff in previous years. Fig. 5 shows two sets of diagrams illustrating correlations of seasonal runoff, estimated from snow survey reports as of April 10 and May 10, with required reservoir storage capacity and regulated outflows. In the absence of adequate snow surveys and laboratory studies, various procedures have been used as expedients in estimating probable seasonal runoff in advance, with varying degrees of success.

In many river basins, snow melt constitutes an important influence on flood runoff only when combined with heavy rainfall; it cannot be considered as a

governing limitation. The correlation between snow-cover indexes and flood control capacity requirements in downstream reservoirs is less definite than stated in the preceding paragraph. However, in recognition of the greater flood potentialities during the certain seasons, as indicated by runoff records from previous years, greater flood control capacity may be reserved during these seasons than for the remainder of the year. Correlations of runoff with

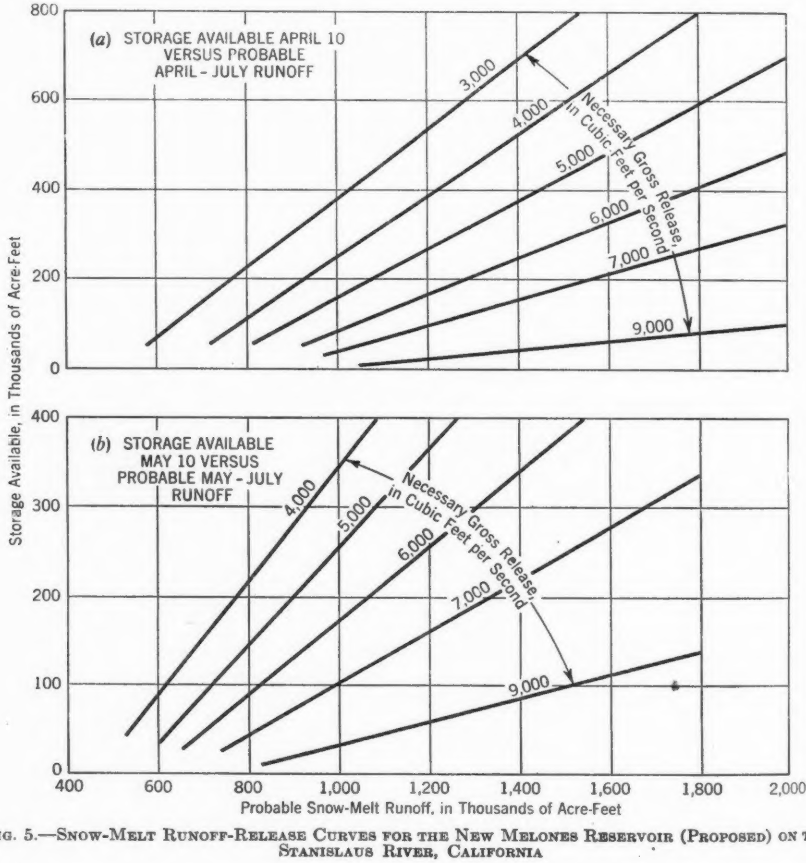


FIG. 5.—SNOW-MELT RUNOFF-RELEASE CURVES FOR THE NEW MELONES RESERVOIR (PROPOSED) ON THE STANISLAUS RIVER, CALIFORNIA

some "basin mean wetness index" may provide a reasonable basis for varying the flood control capacity reservations during the respective flood seasons. Fig. 6 illustrates such a correlation, which was worked out by the Sacramento District Office of the Corps of Engineers for Folsom Reservoir on American River in California. Storage requirements are based on the control of flow to a maximum of 150,000 cu ft per sec at Fair Oaks, Calif. In this case, the "wetness index" parameters are in terms of inches of total precipitation during the preceding 60 days. For snow cover below El. 5000, the wetness index from Fig. 6 is increased by twice the water content in terms of inches over the entire

drainage area. In some basins, a "ground-water index" may serve a similar purpose. The best correlation must be determined from hydrologic studies for each project.

To understand the principles and the criteria that should determine the allocation of storage capacity for flood control in multiple-purpose reservoirs, it is necessary to consider certain aspects of flood control in general. There

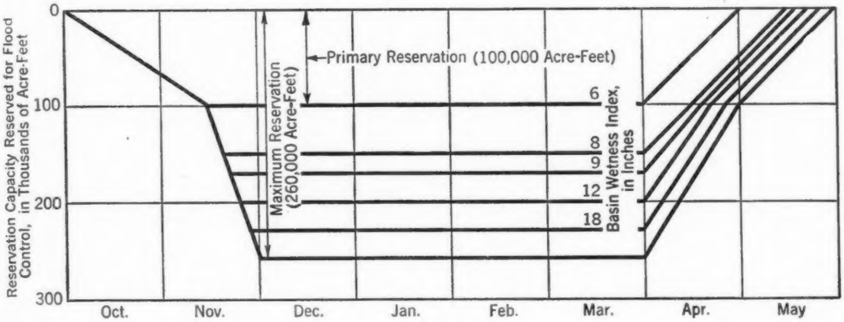


FIG. 6.—FLOOD CONTROL OPERATION DIAGRAM FOR FOLSOM RESERVOIR, AMERICAN RIVER, CALIFORNIA

are two primary methods of providing flood control, and as a rule both are essential for satisfactory results. One is to increase the nondamaging capacity of downstream floodways by channel improvements and by the construction of levees or flood walls; the second is to reduce flood magnitudes by temporarily storing part of the runoff during flood periods in reservoirs. In many cases, appropriate land-use practices will serve to increase the absorption of rainfall by the soil; and, to the extent that this absorption is accomplished during important floods, such practices will help in reducing floods just as has the storage of water in reservoirs.

It is seldom that adequate flood control can be provided by reservoirs alone, with the possible exception of the protection of limited areas very near the reservoir. As a rule it is profitable (and to some extent essential) to provide sufficient channel capacity downstream to carry at least moderate floods, reserving reservoir storage capacities for impounding water during relatively short periods of high flood discharges. It should be observed that the flood control storage requirements in any reservoir vary directly with the permissible rates of outflow during critical flood periods (that is, storage = inflow −outflow). Consideration of downstream channel capacity is inseparable from the determination of flood control storage requirements in any reservoir.

There are three general classes of floods to be considered in determining the degree of protection that should be adopted for a system of channel improvements and for a flood control reservoir:

1. The first class may be designated as "ordinary floods of record" in the given drainage basin—namely, floods that are reasonably certain to be equaled in magnitude one or more times within the estimated life of the project.

2. The second class includes floods exceeding the "ordinary floods," and equal to, or less than, the "standard project flood" for the particular drainage area involved. The "standard project flood" corresponds to a flood that would be exceeded in magnitude only on very rare occasions, and thus constitutes a standard for the design of structures that would provide a high degree of flood protection, as determined by flood potentialities of the drainage system involved without regard for localized economic or other practical limitations of individual projects. The standard project flood would normally be substantially less than the "maximum probable" flood that might occur with the worst combination of meteorologic and hydrologic conditions. In most cases, the standard project flood should equal or approximate the flood that would result, under existing or specified conditions of basin development, if the most critical storm of record in the region should occur over the drainage area involved when hydrologic conditions (including snow-melt potentialities) were reasonably favorable for flood runoff. Although, by definition, the standard project flood is a flood of such high magnitude as to be considered exceptionally infrequent, it is reasonably certain to occur eventually over the drainage basin concerned.

3. The third class of floods includes those ranging in magnitude from the standard project flood to the "maximum probable" (sometimes referred to as "maximum possible"), or the greatest flood that would occur if the most severe flood producing combinations of meterorologic and hydrologic conditions to which the basin appears to be reasonably susceptible should arise. The maximum probable flood is a "potential" flood that could occur in this given basin, but is extremely unlikely to occur.

Flood control works, like other public works, must be justified to warrant expenditure of the public funds required. It is not the purpose of this paper to deal with the evaluation of flood control benefits; but, since such evaluations are essential elements in the determination of appropriate storage capacities to be provided in reservoirs for flood control purposes, it is desired to call attention to certain primary considerations.

If it were economically feasible and practical to provide flood control works adequate for complete protection against all floods up to the maximum probable event, the problem would be greatly simplified. Since this is seldom practicable, it is necessary to decide how much money can be properly invested for flood protection. In making this decision it is necessary to consider both tangible and intangible benefits. The terms "tangible benefits" and "intangible benefits" are used in this paper in a limited sense, referring only to susceptibility to evaluation in monetary terms. For example, "tangible benefits" can be evaluated on a monetary basis, subject to uncertainties somewhat comparable to those attending other types of engineering estimates; thus:

(1) Reduction of damages to structures, lands, communication facilities, utilities, and other stationary property within the flood plain;

(2) Reduction of damages to movable stocks and supplies stored within the flood plain;

(3) Reduction of crop losses in rural areas (sale value, or investments if replantable);

(4) Reduction of losses from interruptions in normal business and industrial activities in the community that are attributable to floods;

(5) Reduction of interruptions in communications that are incident to floods;

(6) Enhancement of property values in protected areas (estimates of these "tangible" benefits usually being limited to apparent increases in property values corresponding to higher-class utilization permitted by protection from floods); and

(7) Reduction in flood fighting and relief costs.

The "intangible benefits" cannot be assigned definite dollar values, although they are recognized to be of great significance, in some cases outweighing tangible benefits in importance. Intangible benefits are:

(*a*) Protection of life and health (that is, reduction of hazards to occupants of protected area, flood fighting and relief personnel, users of transportation facilities subject to flood dangers, crews of rivercraft, etc.);

(*b*) Prevention of social dislocations and distress incident to major flood disasters;

(*c*) Improved general welfare of community resulting from higher standards of development in protected area, with incidental increase in production, higher earning capacities, and improved living conditions in the community at large;

(*d*) National benefits resulting from reduction of interruptions in interstate communications and general benefits derived from increased production, and improved welfare of populace directly affected by protection; and

(*e*) Increased national security resulting from protection of industries and communications against interruption by floods during times of war, and greater national strength incident to increased industrial development and improved general welfare of the people.

In determining the storage capacity to be allocated to flood control in any reservoir, the tangible and intangible benefits to be gained from various degrees of control of the three classes of floods previously discussed must be considered. In estimating these benefits, it is usually found that by eliminating the frequently recurring damages caused by "ordinary floods of record" the major part of the average annual "tangible" benefits that can be attributed to the protection project can be obtained. These benefits result in spite of the fact that a flood comparable to, or exceeding, the standard project flood may cause vastly greater damage than any single event of record in the particular river basin. However, provision of a partial degree of protection for an area suitable for industrial or residential use may serve to encourage intensive development in the protected area under a false sense of security, with the result that extensive loss of life and property may result in the event of a flood exceeding the design capacity of the project. In many cases, without protection against a flood reasonably comparable to the standard project flood, a supposedly "protected area" may be in imminent peril.

It is apparent that the several intangible benefits that are dependent on "security" warrant a substantially greater expenditure for dependable flood

control in some instances than could be justified by measurable "tangible" benefits alone. In this connection, it is observed that annually large sums of money are spent in the United States for fire insurance on buildings and their contents. The security received by each property owner is considered justification for payment of insurance premiums, even if his building never burns down. In a similar sense, a substantial premium for a high degree of security against floods is usually justified in residential and industrial areas, even though there is some possibility that a flood approaching or exceeding the standard project flood might not occur in the particular basin under study within the estimated life of the project. Intangible benefits dependent on "security" against great floods must be given proper credit (in addition to the tangible benefits from control of the more frequent floods), when deciding on capacities to be selected for flood control purposes.

THEIR USE FOR NAVIGATION

BY ROBERT J. PAFFORD, JR.[9]

INTRODUCTION

The Missouri River Basin is the scene of a widespread, multiple-purpose, water use and control program. The technical phases of the basic program, commonly referred to as the Pick-Sloan plan, are being developed under the leadership of the Missouri Basin Inter Agency Committee, with the able and enthusiastic cooperation of many federal, state, and local agencies.

Although many other features are incorporated in the Missouri Basin program, reservoirs and storage are fundamental to its objectives. Present plans include some one hundred and five new federal reservoirs, in addition to the existing Fort Peck Reservoir built and operated by the Corps of Engineers and several smaller existing Bureau of Reclamation reservoirs in the basin. Total storage capacity of the entire approved system of federal reservoirs in the Missouri Basin will amount to some 100,000,000 acre-ft. Practically all this capacity will be obtained in multiple-purpose reservoirs.

The extent of control of the Missouri River itself which will result from completion of this reservoir plan is indicated by Fig. 7. For simplicity, Fig. 7 shows only those reservoirs which are at sites on the main stem, or on lower basin tributaries at sites close to the main stem. The total area of the Missouri Basin is 530,000 sq miles, divided as follows:

	Sq miles
To be controlled by reservoirs in plan	330,000
Not controlled by reservoirs	200,000

These reservoirs are a part of a comprehensive water use program for the control of destructive floods, expanded irrigation, improvement of navigation on inland waterways, hydroelectric power generation, and other collateral and incidental beneficial purposes such as stream sanitation, water supply, recreation, and wildlife uses. The primary emphasis in this paper is placed on how the requirements of navigation are to be served by the multiple-purpose reservoir system being constructed in the Missouri Basin.

FLOW REGULATION REQUIREMENTS FOR NAVIGATION

Reservoir regulation is needed for navigation on the Missouri River. Also, because of the Missouri River's large contributions to the flow of the Mississippi River, water stored in the Missouri Basin is of importance to navigation on the Mississippi River, particularly in the middle reaches between the mouth of the Missouri River, a few miles above St. Louis, and the mouth of the Ohio River, at Cairo.

The existing navigation channel project on the Missouri River provides for a channel 9 ft deep between Sioux City, Iowa, and the mouth to be obtained by revetment of banks, construction of permeable dikes to contract and stabilize

[9] Hydr. Engr., Missouri River Div., Corps of Engrs., Omaha, Nebr.

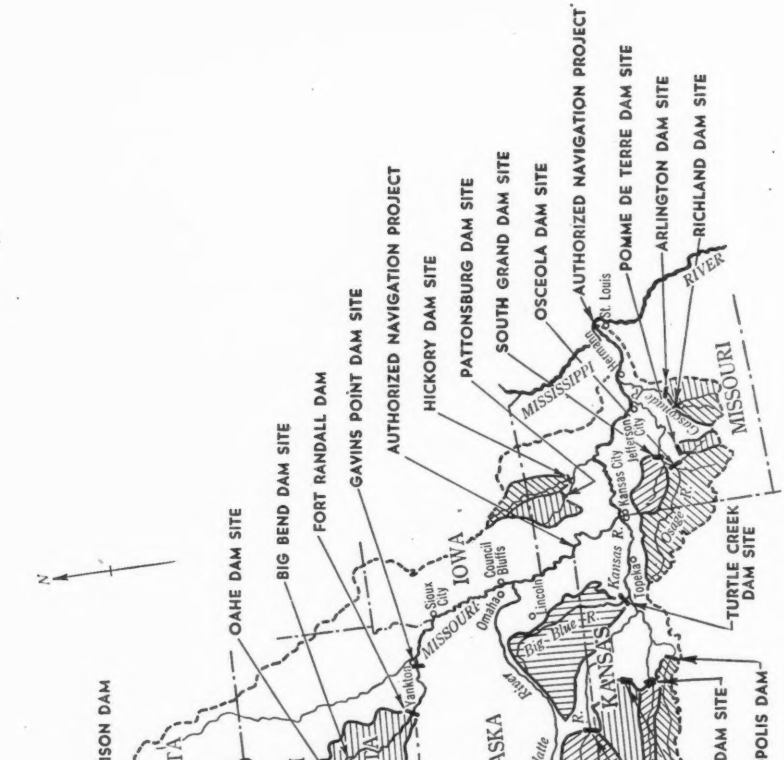


FIG. 7.—FEDERAL RESERVOIRS DIRECTLY AFFECTING THE MISSOURI RIVER

the waterway, cutoffs to improve alinement, closing of minor channels, removal of snags, and dredging as required. The Mississippi River navigation improvement downstream from the mouth of the Missouri River also is an "open-channel" project. With these improvements, substantial minimum river discharges are required to maintain minimum project depths, even with extensive dredging. Increased discharges above the minimum flow requirements decrease dredging requirements and costs, and are of additional benefit to river commerce through improvement of navigation conditions.

Adequate flows for the maintenance of minimum project depths are needed throughout the navigation season. On the Missouri River, because of severe winter ice conditions, the regular navigation season extends only from about April 1 to November 15 at Sioux City and Omaha, Nebr., and from about March 15 to November 30 at Kansas City, Mo., and at points downstream. On the Mississippi River downstream from the Missouri River, navigation continues throughout the year. During the autumn months of normal years (see Fig. 8), natural discharges of the Missouri River ordinarily are quite low,

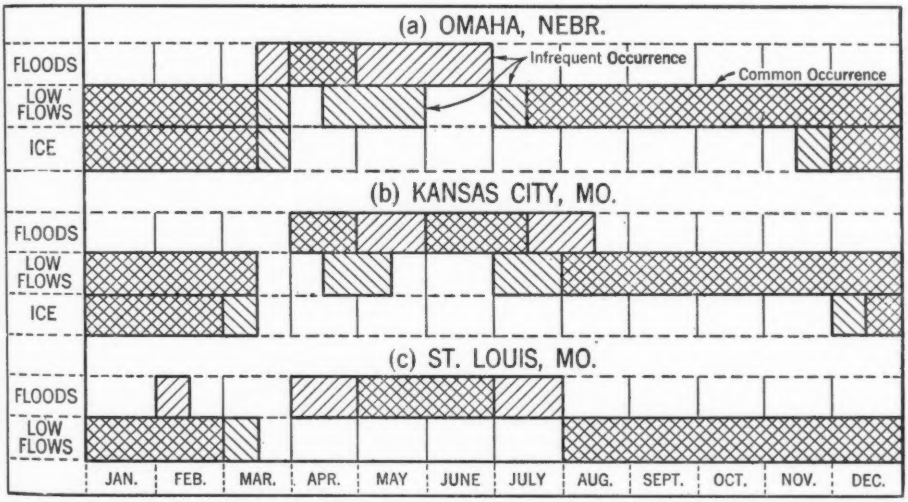


FIG. 8.—FLOOD AND LOW-FLOW MONTHS ON THE MISSOURI AND MISSISSIPPI RIVERS

and often are not sufficient for the Missouri River navigation project. During extremely critical low-flow years (not indicated in Fig. 8) adequate discharges may be available only for a few weeks. On the middle Mississippi River, natural river discharges are inadequate for navigation during the winter low-flow periods of ordinary years, and during the summer and autumn months of low-flow years. On the other hand, adequate discharges are available for these navigation projects during other periods—too much water is available during the flood seasons, and hinders river traffic and damages navigation improvement structures.

The periods of water deficiencies, under natural conditions, result from a great variation in the discharge of the Missouri River both within individual

years and from year to year. There is a characteristic seasonal runoff pattern, as indicated by Fig. 9, with low winter discharges followed by a flood season in spring and early summer when river flows are seasonally high after which discharges rapidly fall off to much lower rates through late summer and autumn. This seasonal runoff pattern is superimposed on a quite variable annual pattern of normal years mixed with wet years, dry years, and droughts, as shown by Fig. 10. The Mississippi River at St. Louis reflects many of the same characteristics as the Missouri River, although variations are not so extreme. The variations in the natural flow of the Missouri River result in a twofold requirement for water supply for navigation: An annual regulation designed to adjust the greatly varying seasonal flow pattern to a more uniform and constant supply throughout the navigation season; and a long-range operation pattern planned to accumulate excess natural stream flows during wet years and to carry this excess water over for use during critical low-flow years and droughts.

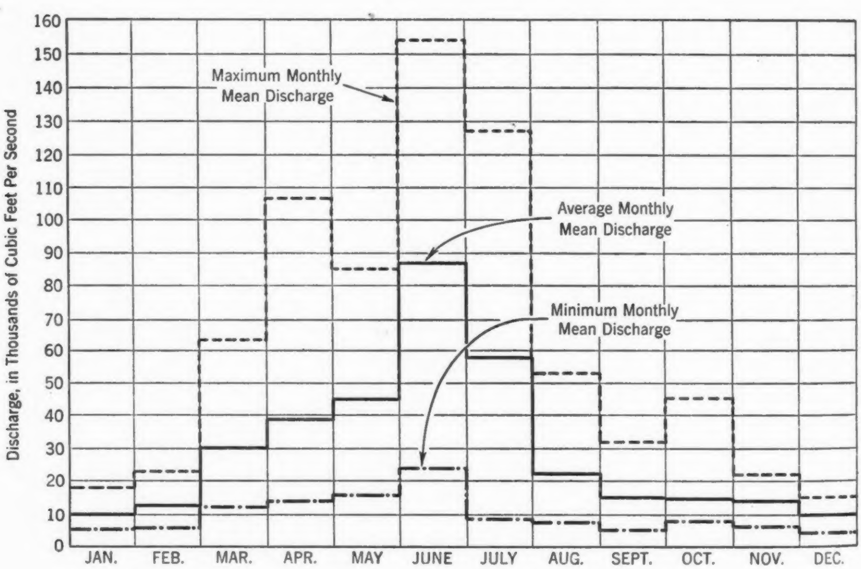


FIG. 9.—NORMAL AND EXTREME MONTHLY RUNOFF, MISSOURI RIVER AT FORT RANDALL (S. DAK.) DAM SITE

JOINT USE OF STORAGE CAPACITY TO SERVE NAVIGATION AND OTHER PURPOSES

The need for annual and long-range storage regulation in the Missouri Basin for navigation is similar to, and consistent with, storage requirements for other purposes. The manner in which the various needs fit together, so that multiple-purpose reservoirs offer the ideal solution, is illustrated by the situation at the large main stem reservoir sites upstream from Sioux City.

Basic requirements at the main stem sites for annual flow regulation for navigation are quite similar to basic requirements for flood control. To obtain

effective flood control along the Missouri River between Sioux City and the mouth, a large amount of flood control storage capacity is necessary at these main stem sites upstream from Sioux City. The flood control requirement is not simply one of providing sufficient storage to reduce excessive natural discharges at the dam sites to safe channel discharge capacities immediately downstream. Large drainage areas in the lower basin which will remain uncontrolled are themselves capable of producing serious floods on the Missouri River. The addition of large releases from the large main stem reservoirs, even though of less than channel-full magnitude at the dam sites, to flood flows from these uncontrolled tributaries, could result in a very ineffective form of flood control; yet, because of the long distances involved, river travel times are too long to permit forecasting of floods from uncontrolled lower basin tributaries in time to permit compensating reductions in releases from the main stem dams. (Water from the lowermost main stem dam will take at least 5 days to reach Kansas City, and 8 days to reach the mouth of the Missouri River.) Therefore for fully effective flood control all along the main stem of the Missouri River, floodwaters impounded in the main stem reservoirs, during the Missouri River flood season, should not be released until the low-water period, following the end of the flood season.

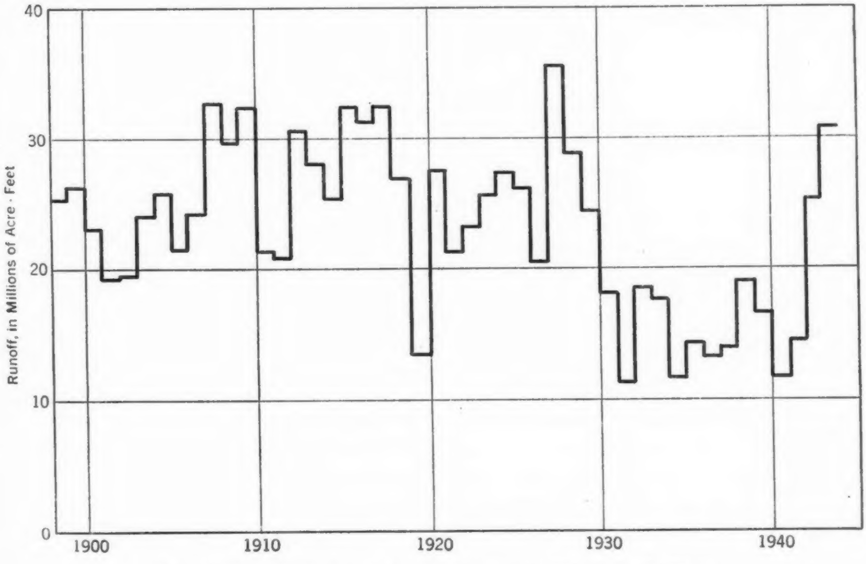


Fig. 10.—Variations in Annual Runoff at Yankton, S. Dak.

This requirement for flood control, quite obviously, is very similar to the annual flow regulation requirement for navigation during normal years. To exploit this opportunity, extensive study programs of historic and potential floods and of variations in seasonal flood control storage requirements were undertaken, and practical possibilities of prediction of seasonal and annual

inflow to the reservoirs were considered. It has been found that a large proportion of the storage capacity that would be required for flood control, alone, also can be utilized to serve the requirements of navigation as effectively as if the storage capacity were reserved exclusively for navigation, without detriment to effective flood control. However, it should be noted that this particular joint-use storage space for both flood control and navigation cannot be used to carry water over from one year to another for navigation. To obtain assured flood control, all the flood control storage space must be vacated in advance of the yearly flood season.

The need for long-range carry-over storage of water supply for navigation at the main stem reservoir sites is paralleled by comparable needs for much of the new irrigation proposed for the Missouri Basin (about 2,000,000 acres of proposed new irrigation to be supplied by water directly from the main stem reservoirs), and also for flow regulation to generate firm power, as well as for other purposes. To meet all these various requirements, large blocks of multiple-purpose carry-over storage are to be provided in the main stem reservoirs, to supplement the natural river flow during low-flow years and droughts. This storage, which is not allocated to any single purpose, will be used primarily to provide a dependable minimum water supply: (1) To supply new irrigation in the basin, and to offset the increasing depletions by new irrigation in the upper basin of the limited natural water supply now available to the lower Missouri Basin during low-flow periods; (2) to furnish the remaining water with maximum efficiency for the navigation project; and (3) to generate a very large amount of marketable hydroelectric power.

The amount of this carry-over storage which can be provided at the main stem sites will be sufficient to raise the dependable annual water yield of that part of the basin above Yankton, S. Dak., from the 11,000,000 acre-ft which was available in years such as 1931, 1934, and 1941, to a minimum average annual yield of almost 17,000,000 acre-ft throughout a critical period such as that from 1930 to 1942. This joint carry-over storage in the main stem reservoirs will thus serve to reconcile the conflicting demands of irrigation and navigation in the Missouri Basin, providing dependably for the reasonable minimum demands of each. Without it there would not be sufficient water available "to go around."

The relationship between navigation and power is a special feature of the joint use of multiple-purpose storage at the Missouri River main stem reservoirs. The head created by the impoundment of water for multiple purposes such as flood control, navigation, and irrigation, coupled with releases through the dams to serve these purposes, results in a large amount of potential power. On first thought, it might appear that the relationship between navigation and power at the main stem reservoir sites would not be harmonious, since large releases for navigation are not regularly needed more than about 8 months a year, and much lower releases would be sufficient for all other purposes except power during the remainder of the year. However, with the system of Fort Peck, Garrison (N. Dak.), Oahe (S. Dak.), and Fort Randall (S. Dak.) reservoirs and the Big Bend (S. Dak) and Gavins Point (S. Dak.) projects (see Fig.

7), it has been possible to work out a plan for maintaining a very high firm power rate without loss of water down the river when it is not needed for navigation. This operation plan takes advantage of the proposed electrical interconnection of all these power plants, and provides for somewhat higher releases in the nonnavigation season at the reservoirs upstream from Fort Randall Reservoir, with recapture of the surplus water in the lowermost reservoirs for retention until the following navigation season. Thus, it has been possible to develop a practical solution which permits both navigation and power to use the same storage capacity jointly with the same full efficiency for navigation, and very nearly the same efficiency for power, as if this storage were utilized exclusively for either of these purposes.

The Missouri River main stem reservoirs form a system of multiple-purpose reservoirs in which nearly all the storage capacity can be used jointly and effectively to serve the needs of one combination or another of basically different purposes. As far as navigation is concerned, there will be:

(1) Top storage zones effective both for flood control and for annual flow regulation for navigation; and

(2) Large multiple-use storage zones which will enable both expanded irrigation and successful navigation, as well as large values for power and other purposes.

The latest studies available indicate that about 50,000,000 acre-ft of the total storage capacity of about 70,000,000 acre-ft proposed for the main stem reservoirs will fall into one or the other of these two multiple joint-use zones. Thus, great economies in cost, and consequent benefits to all the various purposes, result. In addition, the remaining 20,000,000 acre-ft provided for the various purposes not involved with navigation in multiple-purpose reservoir developments at these main stem sites enables this storage, too, to be secured more effectively and at substantially less cost to all purposes involved in reservoirs than would be possible if it were necessary to obtain this storage at other sites.

In connection with the navigation function of these multiple-purpose reservoirs on the main stem of the Missouri River, it is to be noted the reservoirs will supply all the water from storage required for the Missouri River navigation project at Sioux City, and also will furnish much of the water needed to supplement natural flows for satisfactory navigation on the lower Missouri River and on the middle Mississippi River. However, because of larger flow requirements resulting from wider channels and longer navigation seasons, these main stem reservoirs would not completely supply all the navigation water needed on the lower Missouri; and, with these reservoirs completed and in operation, there would still be winter flow deficiencies, from time to time, on the middle Mississippi River. Multiple-purpose tributary reservoirs, at economical reservoir sites on lower basin tributaries (where reservoirs are required as a part of the basin plan, for complete control of Missouri River floods) will serve to supply the additional navigation deficiencies on the Missouri River and, together with other reservoirs outside the Missouri Basin, will provide for navigation on the middle Mississippi River.

Summary

Many supporting pertinent technical studies have necessarily been omitted from this paper. However, it should be emphasized that the detailed technical studies which have been made for the Missouri River projects have proved conclusively that, where there are varied requirements, multiple-purpose reservoirs incorporated in a comprehensive multiple-purpose basin plan can serve any individual need in the basin, such as navigation, fully effectively, with great economies in cost to the various other individual uses. Also, because of economies in reservoir sites and cost, multiple-purpose projects can be developed to serve the various needs, such as navigation, considerably better than would be possible by exclusively single-purpose project developments.

APPLICATION OF GENERAL POLICIES WHEN USED FOR IRRIGATION

By Wesley R. Nelson,[10] M. ASCE

Not one of the irrigation storage reservoirs constructed by the Bureau of Reclamation can be considered as a single-purpose reservoir, although the reservoirs have been planned, built, and operated for that one purpose, and the repayment of the cost of construction is being made only by the irrigation interests. Some measure of flood control, recreation, and fish and wildlife benefits is apparent in each storage reservoir.

An increasing recognition of multiple benefits has been evident since 1933. It has been especially evident in the work of the Bureau of Reclamation since the time plans were prepared for Hoover Dam. With this recognition has come the necessity of determining, within certain limits, the priorities of use among the various purposes. The state and federal governments have given, and are continuing to give, attention to this subject, and their ideas are reflected in the form of legislation. The operation of projects for irrigation and other purposes is dependent on federal and state policies and on contracts with the beneficiaries. Designs and operations of reservoirs have been changed to keep pace with these factors.

There is not much uniformity, and there is no standardization, apparent in the measures that have been adopted from year to year in the allocations to different purposes or in the methods of operation; but, to some extent, the examples given in this paper will explain the principles involved. The operating characteristics cannot be divorced entirely from the financial ones, because in Bureau of Reclamation projects the two are interdependent. Consequently, information on the cost allocations will be treated briefly in some cases.

The Rio Grande Project in New Mexico and Texas, which covers 155,000 acres of irrigated land, extends nearly 180 miles along the Rio Grande upstream and downstream from El Paso, Tex. The international boundary between the United States and Mexico, beginning at a point immediately above El Paso, is formed by the river. Water regulation and storage are provided by the Elephant Butte Reservoir, with a capacity of 2,219,000 acre-ft in 1940 (the date of the latest survey), 22 miles above the project lands, and the Caballo Reservoir with 346,000-acre-ft capacity, immediately above the project lands in New Mexico. A power plant of 24,300-kw installation is situated at Elephant Butte Dam.

Caballo Dam and the power plant at Elephant Butte Dam were added to the project works about 23 years after Elephant Butte Dam was completed. Caballo Dam was constructed in part to provide control of arroyo floods, but its principal function was to provide after bay storage capacity to reregulate releases from Elephant Butte Reservoir and make possible the generation of a large block of salable power at the Elephant Butte plant.

[10] Asst. Commr., Bureau of Reclamation, U. S. Dept. of the Interior, Washington, D. C.

The initial contract with the project water users, signed in 1906, called for repayment to the federal government of all costs of Elephant Butte Dam and Reservoir. In 1907, $1,000,000 was declared nonreimbursable by appropriation from the General Treasury in accordance with a treaty with Mexico (signed May 21, 1906) whereby 60,000 acre-ft of water would be stored annually in Elephant Butte Reservoir and delivered to Mexico at a point near Ciudad Juárez. The treaty contains a schedule of water delivery for each month, but the supply is diminished in years of extraordinary drought or serious accident to the irrigation system in the United States. Although there was a storage allocation to flood control of 416,000 acre-ft, which covered the upper part of the reservoir from the inlet of the cylindrical gates (El. 4396) to the spillway crest (El. 4407), there were no nonreimbursable funds allotted for this purpose. After Caballo Dam and the power plant were completed (in 1938 and 1940, respectively), the cost allocations and the repayment contracts were revised. Approximately $1,500,000 was transferred to construction funds by the United States State Department to cover the flood control allocation for the Caballo Dam. This action was a part of the program of the International Boundary Commission for flood control and river rectification along the international boundary. An agreement was reached between the United States and the project water users whereby the remaining part of the costs for Caballo, the cost of the power plant and facilities, and the costs of construction of Elephant Butte Dam and appurtenant works were to be repaid solely from net power revenues. The reimbursable costs of the storage works were divided between irrigation and power; the allocation to irrigation to be repaid without interest, and the allocation to power with interest at 3%.

A summary of storage and cost allocations resulting from the various contracts and agreements is given in Table 2.

An agreement on the operation of Caballo Dam was reached with the State Department, whereby 100,000 acre-ft of storage would be available for flood control from June 1 to November 1 of each year. Although the major part of the costs of storage works must be repaid from revenues derived by sale of power, water may be released from Caballo Dam only when needed for irrigation or when spilled during floods after both reservoirs are encroaching on their flood control pools. It is obvious that the reservoirs must be operated very carefully to obtain the maximum power development, and at the same time to stay within the flood control limitations and avoid all discharge of unusable water from Caballo Dam. This situation is further complicated by provisions in the compact among Colorado, New Mexico, and Texas, which governs the distribution of use of Rio Grande waters above Fort Quitman, Tex. (80 miles below El Paso).

Benefits to fish and wildlife, recreation, and sediment detention have always been substantial at Elephant Butte Reservoir, but no allocations have been made to these uses. The City of El Paso obtains a part of its water supply from the project works. When the project was first planned, the city was given an opportunity to participate and to receive a water supply. It elected to continue to procure its supply from underground sources. Recently, the increased population of the city, the influx of industry, and the establishment

TABLE 2.—Storage and Cost Allocations Resulting from Various Contracts and Agreements Involving the Rio Grande Project in New Mexico and Texas

Item No.	Use allocation	Elephant Butte Dam and Reservoir (New Mexico)	Project diversion, distribution, and drainage system	Power system (direct cost)	Caballo Dam and Reservoir (New Mexico)	Totals
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	Purpose	Multiple[a,b]	Irrigation	Power	Multiple[a]	....
	(a) Storage Allocations, in Acre-Feet					
	Initial Allocations—					
2	Flood control	416,000[c]	....	....	100,000	516,000
3	Irrigation	2,222,860	....	....	245,000	2,467,860
4	Total	2,638,860	....	....	345,000	2,983,860
	Allocations as of 1940 Survey—					
5	Flood control	388,700[c]	....	....	100,000	488,700
6	Irrigation	1,830,300	....	....	245,000	2,075,300
7	Total	2,219,000	....	....	345,000	2,564,000
	(b) Cost Allocations, in Dollars, Resulting from Contracts and Agreements					
	Prior to 1937—					
8	Storage for Mexico	1,000,000	....	....	....	1,000,000
9	United States irrigation	4,246,408	11,269,087	....	....	15,515,495
10	Total	5,246,408	11,269,087	....	....	16,515,495
	Prior to October 31, 1946—					
11	Storage for Mexico	1,000,000	....	....	....	1,000,000
12	United States irrigation	2,123,204[d]	11,402,130	....	383,954[d]	13,909,288
13	Flood control and river rectification	....	....	....	1,510,654[e]	1,510,654[e]
14	Power	2,123,204[d]	....	2,921,290	383,954[d]	5,428,448
15	Total	5,246,408	11,402,130	2,921,290	2,278,562	21,848,390
16	Total estimated construction cost	5,246,408	11,778,244	5,549,575	2,278,562	24,852,789

[a] Flood control, irrigation, power, and fish and wildlife benefits. [b] Recreation and sediment detention. [c] Considered as available for flood control but not specifically allocated by federal regulation or legislation. [d] To be repaid from net power revenues. [e] The United States State Department allotted $1,498,240 of Caballo Dam funds for flood control and contributed $12,413.73 for preliminary surveys and investigations. These funds are not reimbursable.

of a large army post produced a much greater demand on the underground reservoir than could be met by recharge. Since all the waters stored at Elephant Butte were required for project lands, it was necessary for the city to purchase lands and thus obtain rights to water that could be used for domestic purposes.

It was necessary to operate the project storage works for flood control in the spring and summer of 1942. Unusually large inflow into the reservoir in May and June, 1941, was followed by heavy runoff from the basin above the reservoir in the following spring. The outflow from both Elephant Butte and Caballo reservoirs was held substantially below the rate of 11,000 cu ft per sec as required by the agreement with the State Department; but some damage was caused in areas near Hot Springs, N. Mex., between Elephant Butte and Caballo reservoirs, where property had encroached on the flood plain.

Fig. 11 represents a chart from the "Rio Grande Project History of 1942," showing the operations during the flood control period.

Under normal conditions, the discharge from Caballo Dam is entirely for irrigation, and Elephant Butte Dam and power plant are operated to avoid

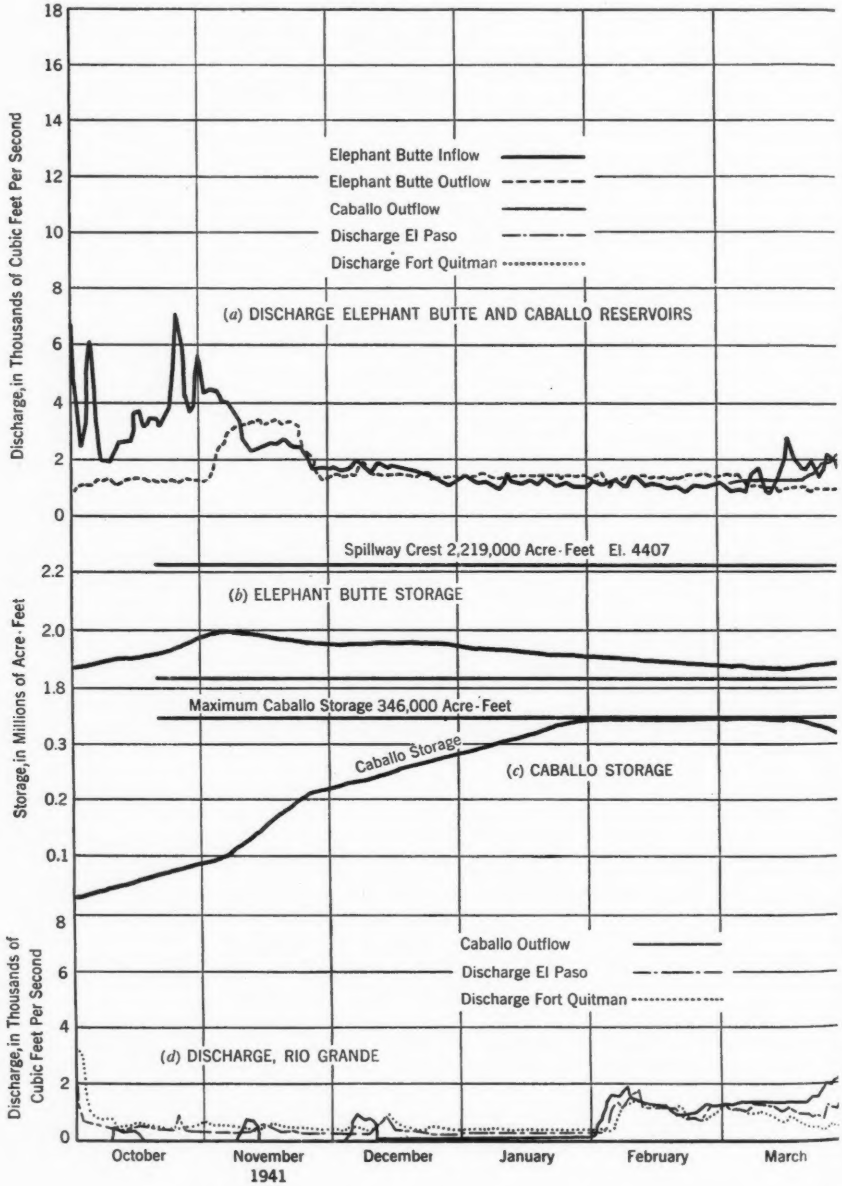
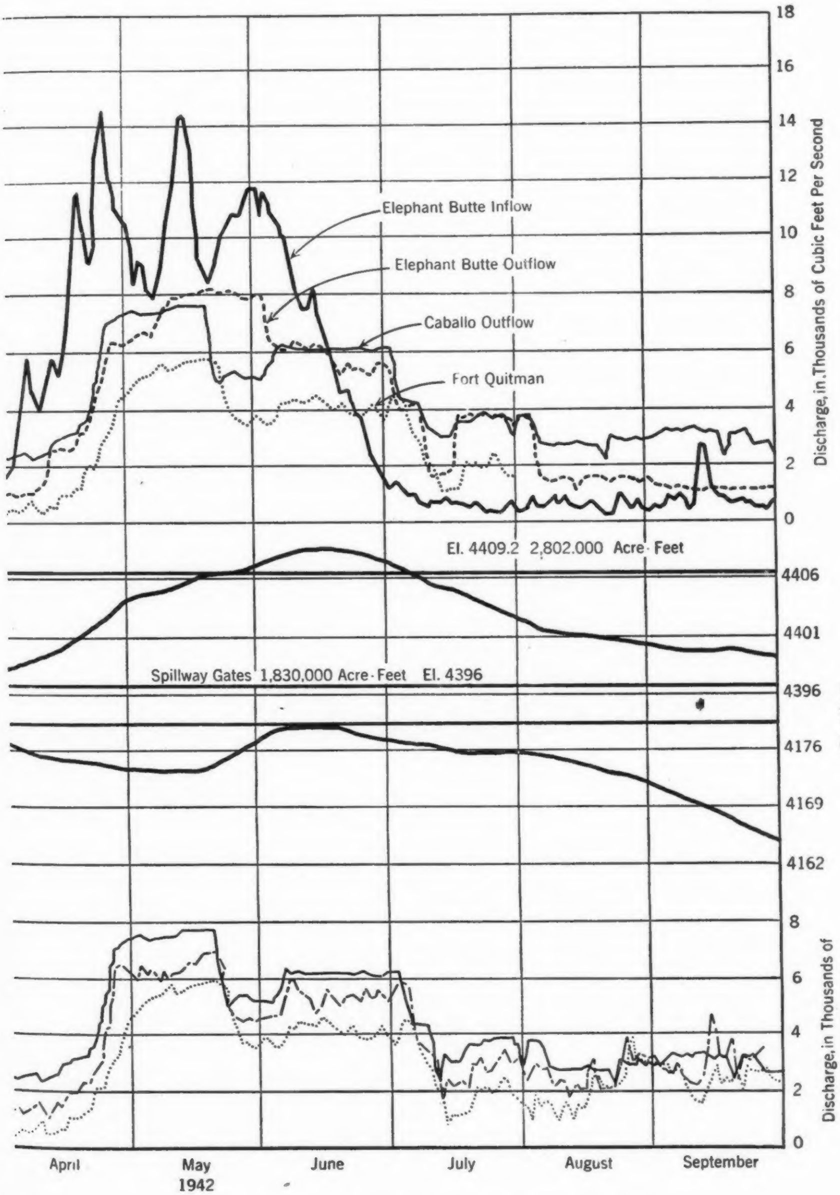


FIG. 11.—OPERATION OF ELEPHANT BUTTE AND CABALLO RESERVOIRS IN

raising the elevation of Caballo Reservoir to a level that would make spills of nonirrigation water necessary. Farmers on the project inform the ditch rider when they will need water and how much will be required. This information is passed on to the project office where data are compiled and orders given for



New Mexico for the Period from October 1, 1941, to October 1, 1942

the release of water from Caballo. The operator at Elephant Butte Reservoir is notified of the quantity of water that can be spilled from the reservoir during each month. On some occasions, particularly in the spring, when it is necessary to evacuate the flood control pool at Caballo Reservoir, operations of the power plant are restricted.

These factors are the principal ones to be noted in the Rio Grande case. Decisions, with regard to allocations, were reached only when exigency demanded, as the circumstances indicated, and without an analysis of all benefits and potential allocations. However, the project works are so designed that they can be operated satisfactorily for irrigation, flood control, power development, and other purposes.

Although considered originally as a single-purpose project, the Alamogordo Reservoir on the Pecos River, 247 miles above the Carlsbad (N. Mex.) Project, which it serves, has captured or reduced the peak of several floods since 1937, when the dam was under construction. The present capacity of the reservoir is about 132,000 acre-ft. Recognition of its flood control potentialities is expressed in a federal act (Act of August 11, 1939; 53 Statute 1414) which provides for the determination, by the Corps of Engineers, of the benefits the reservoir affords. There are some fish and wildlife and recreational benefits, and prior to 1946 the permissible drawdown was such that only 5,000 acre-ft remained in the reservoir. In 1946, the water shortage on the Carlsbad Project became so acute that the reservoir was lowered to 1,500 acre-ft, the maximum drawdown that could be accomplished without damage to the outlet valves. No loss of fish was apparent.

Conchas Dam on the Canadian River in east central New Mexico, 35 miles northwest of Tucumcari, was completed by the Corps of Engineers in 1939. Storage capacity amounting to 600,000 acre-ft was assigned: 100,000 acre-ft to sediment detention; 300,000 acre-ft to irrigation; and 200,000 acre-ft to flood control. Storage capacity for flood control is in that part of the reservoir above the permanent crest of the dam spillway.

The Bureau of Reclamation is building the 38-mile canal from the Conchas Reservoir to the project lands and the irrigation distribution and drainage systems for a project area of 45,000 acres which surrounds the City of Tucumcari.

None of the costs for the reservoir is to be repaid by the water users. The Corps of Engineers operates the dam, reservoir, and all outlet works including the one for the irrigation canal. Releases of irrigation water are made as requested by the Bureau of Reclamation.

There is considerable fishing and boating at Conchas Reservoir, but no allocations have been made for such benefits. It is probable that some fish will be lost from the reservoir through the irrigation outlets. This condition might be rectified by screening the outlets or by placing a trap in the main canal. A small 150-kw plant provides power for the dam and camp operations. Water for operation of the plant is taken from any water available in the reservoir, without reference to a specific allocation.

The principal features of the Altus Project in southwestern Oklahoma are the Altus Dam and Reservoir on the North Fork of the Red River and a canal

and distribution system for the irrigation of approximately 60,000 acres south of the dam. The reservoir capacity is 188,414 acre-ft. The allocations made by the Bureau of Reclamation for regulation purposes, and the cost allocations, as established in the "Findings of Feasibility" (dated January 21, 1941) were as follows:

Allocated to:	Acre-feet	Costs
Silt	43,000	....
Municipal supply	4,800	$1,080,000
Irrigation	103,850	2,000,000
Flood control	36,764	1,130,000
Unemployment relief	....	1,390,000

The allocation of space for flood control is above the crest of the ungated spillway. The Work Projects Administration participated in the unemployment relief. The estimated cost of the project has increased since the "Findings of Feasibility" but the allocations have not been changed.

This project is one for which the Secretary of War is to prescribe regulations for use of storage allocated to flood control under the terms of Section 7 of the Flood Control Act of 1944 (58 Statute 890). The tentative agreement is that the flood control discharge facilities shall be operated under the direction of the district engineer of the Corps of Engineers whenever the pool stage reaches the crest of the ungated spillway. The district engineer then directs the operations of the discharge facilities to prevent flood damage below the reservoir and to limit the pool stage to an elevation 3 ft above the crest of the ungated spillway as far as possible.

Hoover Dam, one of the most successful multiple-purpose projects in the United States, is located on the Colorado River, 420 miles above its mouth, where the river forms the boundary between Nevada and Arizona. The dam is 8 miles east of Boulder City, Nev., and 71 miles northwest of Kingman, Ariz. The reservoir, Lake Mead, has a capacity of 31,142,000 acre-ft. The power plant, located at the toe of the dam, will have a total capacity of 1,317,500 kw, of which 1,030,000 kw is now (1948) installed.

The purposes for which the reservoir and power plant were built, as set forth in Section 1 of the Boulder Canyon Project Act (Act of December 21, 1928; 45 Statute 1057), are:

1. Control of floods;
2. Improvement of navigation and regulation of the flow of the Colorado River;
3. Provision for storage and for the delivery of the stored waters for reclamation of public lands and other beneficial uses within the United States; and
4. Generation of electrical energy to make the project a self-supporting and financially solvent undertaking.

Engineering studies indicated that the lower 300 ft to 360 ft of the reservoir should be allotted to silt and sediment detention; the next 155 ft to 215 ft to active storage or river regulation; and the upper 75 ft to flood control. The approximate reservoir capacities are 3,000,000 acre-ft for silt detention;

20,000,000 acre-ft for active storage and river regulation; and 9,000,000 acre-ft for flood control.

The initial legislation provided that the cost of all the works would be repaid in 50 years with 4% interest through the sale of stored water and electrical energy, but that no charge should be made for water stored for the Imperial and Coachella valleys in California. The sum of $25,000,000 of the construction cost was allocated to flood control and was to be repaid to the United States out of a percentage of the revenues which were in excess of the amount needed to meet periodic payments during the period of amortization. The Boulder Canyon Project Adjustment Act (Act of July 19, 1940; 54 Statute 774) revised the repayment plan. It provided that the payment of the $25,000,000 allocation to flood control was to be deferred to the period starting June 1, 1987, and to be repaid without interest. The remainder of the cost of the dam and power plant was to be repaid with 3% interest from revenues from the sale of power and water. The costs of operation and maintenance were to be met by an advanced payment each year of generating charges. As of May 31, 1945, the end of the project's fiscal year, $37,700,000 had been returned to the Treasury from the sale of water and power. Generating charges for 1945 totaled approximately $1,630,000.

Among the unique provisions of the act were those providing for payment of $300,000 per yr from 1938 to 1987 to each of the states of Arizona and Nevada and for the transfer to a special fund in the Treasury, designated as the Colorado River Development Fund, of $500,000 a year from 1938 to 1987 for studies, investigations, and construction of projects in the Colorado River Basin.

In accordance with the terms of the initial authorizing legislation, contracts for the sale of water and power were obtained before construction was initiated. After the adjustment act was passed, the contracts were amended and arrangements made for the power allottees to operate the electrical generating and transmission system. The Bureau of Reclamation, however, operates all valves and gates which control the flow of water from the reservoir.

It will be noted that the allocations of reservoir capacity do not apply specifically to the purposes for which the project was authorized. Furthermore, the policies for repayment differ from the general ones pertaining to irrigation and flood control in that repayment is required for flood control and is made for irrigation with interest. The recreational and fish and wildlife benefits are very great at Lake Mead, but allocations have not been made for these purposes.

The water stored in Lake Mead must be conserved for municipal and irrigation uses downstream; therefore, power and flood control releases must be regulated in such manner that the water may be used to full advantage on the projects below the dam.

Among the more important projects already constructed below Hoover Dam are the Parker Dam power plant and the pumping plant of the Los Angeles aqueduct immediately upstream from Parker, Ariz.; the Palo Verde Irrigation Project near Blythe, Calif.; the Headgate Rock Diversion of the Colorado River Project of the Indian Service; and the diversion dams for the Imperial Valley and Yuma projects near Yuma, Ariz. These projects are

from 150 miles to 300 miles from the dam. Their needs for water fluctuate from day to day; and, on account of the long distances involved, careful scheduling must be followed to avoid wastes on the one side or water shortage on the other. In addition, water releases and river control are required for the delta area in Mexico, under the terms of the Mexican Treaty, which became effective on November 8, 1945. These requirements make it desirable to route all water requests to a river control officer of the Bureau of Reclamation, who compiles the data, coordinates it with the required operations of Lake Mead for power development and flood control, and designates the quantity and time of water releases from Hoover Dam.

The Davis Reservoir is being built (1948) in Arizona-Nevada 65 miles downstream for power development and river regulation. When completed, this structure should aid materially in increasing the efficiency of operation of Hoover Dam. As the development of the Colorado River Basin progresses and the states of the basin reach an agreement on the allocation of the river waters, the importance of Hoover Dam as the key structure in the river basin development will become increasingly apparent.

An enormous amount of study has been given to the design and the operation of the Columbia Basin Project, in Washington, to obtain the maximum control and use of the Columbia River waters and to provide the greatest benefits for multiple purposes.

The Grand Coulee Dam, the principal feature of the project, is situated on the Columbia River, 94 miles northwest of Spokane, Wash. Other features of this project are:

(*a*) The 9,500,000 acre-ft reservoir back of the dam;

(*b*) Power plants situated one at each end of the dam, which will have a final capacity of 1,944,000 kw, 648,000 kw of which is installed;

(*c*) The pumping plant, with a capacity of 16,000 cu ft per sec and 650,000 hp, which will raise water a maximum of 360 ft from the reservoir to the irrigation project works;

(*d*) A regulating reservoir of 1,202,000-acre-ft capacity; and

(*e*) Main canals (440 miles) to serve the project area of 1,022,000 acres, lying in the Grand Coulee south of the dam.

The power plant is connected to the high voltage power network of the Bonneville Power Administration, which markets the power from the Bonneville (Ore). plant, built by the Corps of Engineers at a site 450 miles below Grand Coulee Dam.

The principal purposes served by the Grand Coulee Reservoir are navigation, flood control, irrigation, power and river regulation. Specific allocations of storage capacity have not been made to different purposes, the benefits being obtained through appropriate regulation of the reservoir.

An indication of the elements that will be considered in the operation of the project can be obtained from the final cost allocation determinations that were made in a report by the U. S. Department of the Interior, submitted

to Franklin D. Roosevelt, then President of the United States, and to the Congress:[11]

Irrigation—including power for pumping	$341,929,994
Present commercial power	113,827,243
Downstream river regulation	30,272,991
Flood control and navigation	1,000,000
Total	$487,030,228

It was decided that the costs of constructing the project works should be met by (1) repayments by the water users within their limits to repay, (2) a nonreimbursable allocation to navigation and flood control benefits, and (3) net revenues from the sale of power generated at Grand Coulee Dam and generated at plants downstream, when the power output was benefited by the river regulation provided by Grand Coulee Dam. The basis for repayment of the reimbursable costs is given in the report.[12] For example, the cost requirements and the revenues needed to repay total reimbursable costs plus interest at 3% on investment allocated to power (over repayment period ending in 2017, inclusive), are:

Item	Description		Cost
	Requirements:		
1	Reimbursable construction cost		$486,030,228
2	Replacements		72,920,000
3	Other operating expenses		151,567,042
4	Interest on unamortized balances of investment allocated to power		70,786,815
5	Total		$781,304,085
	Revenues:		
	From Water Users—		
6	For pumping power	$50,500,000	
7	Construction cost repayment	87,465,000	
8	Total revenues from water users		$137,965,000
9	Remainder required from commercial power		$643,339,085
10	Revenue for river regulation at the Bonneville project		9,378,500
11	Remainder required from sale of power generated at Grand Coulee		$633,960,585

The reimbursable construction cost (item 1) is equal to the total cost of the project ($487,030,228) less $1,000,000 which is allocated to navigation and flood control. Items 3 and 8 do not include operation and maintenance expenses of the irrigation system, amounting to several million dollars annually.

[11] *House Document No. 172*, 79th Cong., 1st Session, 1945, p. 21, Table 8.
[12] *Ibid*, p. 26, Table 11.

The sum required from the sale of power generated at Grand Coulee (item 11) is in excess of that required by law to the extent of about $70,786,815, which is equivalent to the interest on the investment allocated to power.

Items 1 to 11 show that there was no allocation of part of the costs to "fish and wildlife" or to "recreation." The benefits to these purposes are substantial, although there are some offsetting damages to fish propagation. The Grand Coulee Dam blocks the run of salmon into the spawning grounds in the upper reaches of the Columbia. Runs are being reestablished in tributaries below the dam, requiring a considerable expenditure of money for traps, hatcheries, transportation equipment, and operations.

Another feature of the Columbia River Project is the proposal to secure returns from the benefits to present and future downstream power plants; but, in the allocation of repayments, the only revenues anticipated at present (1948) are those from the Bonneville plant.

Several more of the fifty-seven operating projects of the Bureau of Reclamation could be described to point out certain distinguishing characteristics of design and operation, but the general principles would be similar. The Rio Grande Project is typical of those where there are definitely recognizable multiple purposes. On this project reservoirs can be operated for many purposes, without appreciable conflict, provided that the various potential uses are recognized in the planning stage and the designs are prepared accordingly.

The design, and particularly the operation, of reservoirs on federal irrigation projects are not dependent solely on engineering considerations, river discharge characteristics, or the regulation of stream flow for optimum benefits for all purposes. They are influenced in considerable degree by financial and and legislative matters which apply to each separate project.

It is extremely desirable to analyze all potentialities of proposed projects to avoid costly reconversion or duplication of construction features; and it is desirable, where feasible, to build and operate the works for all practicable purposes. At the same time, there should be recognition of all benefits in multiple-purpose projects and general uniformity and standardization should be provided when cost allocations are determined. These objectives will be attained only as fast as the states and the federal government—and especially federal agencies—make their decisions on water policies. There is much dissimilarity in the approaches of different agencies to problems of investigations and operations, with consequent confusion in the handling of water matters. This situation can be rectified only when an adequate national water policy has been adopted. Then, and only then, will it be possible to attain any appreciable uniformity in the determination of allocations for various purposes in multiple-purpose projects. It is hoped that the impetus afforded by the papers of this Symposium will develop the guidance that is needed so greatly.

COORDINATION WITH THE ELECTRIC UTILITY INDUSTRY

By J. B. Thomas[13]

Foreword

The general background of the extent, character, and cost of multiple-purpose dams in the United States and of the trends established and the problems posed is presented in this paper. A general résumé and discussion of a group of such dams in the southwest, with which the writer has had direct experience is also included.

Multiple-Purpose Dams in General

The building of this type of dam has been almost solely developed as a governmentally financed device based on general public benefits. Taxpaying industry, which must finance itself and otherwise "stand on its own feet," has not found economic justification for such structures.

Relatively early in its history, the United States Reclamation Service found that there was some electrical energy available at its dams over and above that needed to operate the control gates and other equipment. It marketed this power successfully to farmers and to neighboring utilities. The proceeds of these sales were used to reduce the sums to be paid by the settlers for water to irrigate their lands. In all these earlier structures, although the power supply has become a comparatively large income producer, the reclamation objective has remained paramount, and power is still subordinate. The power supply has been coordinated, completely and efficiently, with the other power resources in the areas through sales to existing utilities.

Hoover Dam, which was started in 1930, and placed in operation in 1936, was the first of the great multiple-purpose dams to be built with power production as the primary purpose of the enterprise, and to present a coordination problem of large proportions.

After Hoover Dam was completed, many multiple-purpose dams were undertaken, and many more are scheduled for future construction, practically every one of them with power as its predominant purpose (see Table 3). In many cases, the actual cost of the projects that have been completed has overrun the estimate on which they were authorized. Taking into account such overruns and the rapidly mounting costs of construction, it would appear that the total capital expenditures for the 289 projects listed in line 7, Table 3, may reach a total of $15,000,000,000. The total installed capacity, present and prospective, in the 289 projects is 79% of the 40,360,000 kw of installed capacity of privately owned utilities as of December 31, 1946. The successful coordination of such a great amount of government power with the existing power resources obviously is no small undertaking, and if badly handled government power could be very harmful to the utility industry and costly to ultimate consumers and taxpayers.

[13] Pres. and Gen. Mgr., Texas Electric Service Co., Fort Worth, Tex.

Obviously, the output of completed multiple-purpose dams must be marketed—either by displacing existing sources of power, or by using the dams to take care of their appropriate part of the increases in the demand of the existing market.

TABLE 3.—Multiple-Purpose Dams Involving Electric Power, and Financed by Federal Funds

Line	Description	No. of dams	Kilowatts installed (ultimate)	Estimated cost
1	Completed and in service since 1933	30	6,286,500	$1,661,360,000
2	Steam stations and single-purpose hydro plants built in conjunction with, and because of, multiple-purpose dams	3	342,000	49,260,000
3	Total dams in service	33	6,628,500	$1,710,620,000
4	Under construction	28	3,142,550	872,320,000
5	Authorized and approved	132	11,915,700	3,100,440,000
6	Being actively proposed	96	10,179,300	2,615,500,000
7	Total built, being built and in line for early construction	289	31,866,050	$8,298,880,000

It should be noted that the generation and the sale of electricity in appreciable commercial quantities date from as recently as the 1880's. Invention and development were the results of private initiative and private enterprise. Both steam-electric and hydroelectric generating stations of various characteristics were built, and their operations coordinated. Step by step, large interconnected transmission networks were constructed and operating methods developed. These improvements led, in turn, to the formation of interconnected groups working together, with attendant economies and improved power supply. Today, the United States leads the world in the use of electricity. The outstanding accomplishment of the utility industry was in meeting all the power needs of the nation in full throughout World War II, despite great shortages of equipment, labor, and supplies, although every other commodity was in short supply, or strictly rationed. Morever, this need was met without increasing rates, despite a great increase in the price of supplies used by the utilities, and a large increase in utility taxes. Such results are indicative of the vigor and resourcefulness of the electric utility industry—all without tax remission or subsidy. It stands to reason that, if there were economic justification for a taxpaying individual or group to build such multiple-purpose projects, many would have been so built.

The electric utility industry is willing and able to meet the future power needs of the United States without benefit of subsidy or special privileges, and the industry has the technical skill and experience to make use of the power from multiple-purpose dams to the best advantage when and if it is called upon to do so. Every evidence points to a long-continued growth in the use of electricity. Therefore, existing efficient power resources need not be displaced by multiple-purpose dams. If the new plants are properly scheduled and designed, they can be utilized to carry the new load in conjunction with existing generating facilities and additional base load stations.

Ever since its early beginnings, the electric utility industry has been principally privately owned and partly government owned. For many years the relation between these two sections of the industry was relatively constant. About 95% of the public supply was generated by privately owned utilities, and about 5% by government owned utilities, mainly municipalities. About 1933, the proportion of government owned power production began to increase rapidly. In 1946 it amounted to 18.86% of the total produced for public use, or about 3¾ times the proportion prevailing prior to 1933. Multiple-purpose dams built by governmental financing, with the attendant tax advantage to the users and corresponding loss to other taxpayers, were largely accountable for the increase.

Much of the increased production in public power generating stations has been marketed through existing utility systems. In 1945, privately owned utilities accounted for about 90% of the "revenues from ultimate consumers" and public power about 10%, and the 1946 proportion probably was about the same. The outlet for marketing and coordinating the power from multiple-purpose dams is still predominantly through privately owned utilities.

However, in discussing the problem of coordinating this vast amount of very specialized hydro power with the existing power facilities, certain other problems must be taken into account. Multiple-purpose projects vary widely in respect to cost, desirability, usefulness, and amount and kind of power; but they all have some common economic characteristics which have a direct bearing on coordination and marketing, such as

1. All are more or less the recipients of financing and tax advantages at the cost of the general taxpayers;
2. The power from these dams, contrary to common belief, is not cheap. Its actual cost is often greater than for equivalent power from other available sources; and
3. The cost of many of these dams is so great that, to make them "money out," even under the government formulas used to justify their construction, it is necessary to design them to operate at very low load factors.

The need to show that large power values are inherent in these projects has led to some designs that seem to have little relation to the power requirements of the territory. For example, the engineers laying out multiple-purpose dams involving power and flood control or navigation are furnished a formula (usually in the form of a two-part rate) by the Federal Power Commission, with which to place a dollar value on the power and energy to be produced. These formulas vary widely with localities and with the price of fuel. The "Texas formula" in Table 4 is the one used for the Red River in Texas and Oklahoma. It sets the value of power capacity at \$10.50 per kw-yr and the value of energy at 0.83 mill per kw-hr. The "Virginia formula" in Table 4 was used in connection with the Buggs Island development on the Roanoke River in Virginia. The rate under this formula is \$17.20 per kw-yr plus 3.12 mills per kw-hr. Both formulas are used in fuel-producing areas.

The Division of Power of the United States Department of the Interior furnished a list of proposed multiple-purpose dams in the eastern part of the United States, the output of which must be absorbed by the load of the territory. An estimate of the firm power is given for fifty two of the projects on the long list. The load factors (ratio between average prime power and installed capacity) indicated are:

TABLE 4.—VALUE OF 1,000,000 KW-HR OF ENERGY, IN DOLLARS PER YEAR

Formula	Load Factors				
	100	75	50	25	10
Texas	2,029	2,428	3,227	5,624	12,816
Virginia	5,083	5,738	7,047	10,974	22,754

Load factor (%)	No. of multiple-purpose dams
72	1
50	3
37 to 31	4
29 to 26	4
25	24
24 to 21	5
19 to 15	5
14 to 9	6
25 (weighted average)	52

Local rainfall and runoff conditions greatly affect the design of multiple-purpose dams. A comparison between two diverse areas is instructive. The Columbia River in the northwest has a large dependable flow because it is fed by great snow accumulations and great glaciers, and is replenished by heavy rainfall. The Red, Arkansas, White, and Ouachita rivers in the southwest, on which many multiple-purpose dams are planned are flash rivers lacking dependable flow. The four rivers together have about the same drainage area as the Columbia; yet their total volume of water (floods and all) is only 38% of that of the Columbia.

The federal government has built two multiple-purpose dams on the Columbia River. They are practically completed, except for a few generating units being installed (1948) at Grand Coulee. The federal government has built or financed three, and is building or planning to build fifteen more multiple-purpose dams on the Red, Arkansas, White, and Ouachita rivers. The comparison in Table 5 is indicative of the wide variations between the two sections.

The comparison would be even more striking if estimates for the proposed plants in the southwest were available, as they would be much higher than those shown in Table 4; but, taking the data as they are, for each 1,000,000 kw-hr, of primary energy per year a capital expenditure of $23,818 was necessary

on the Columbia, and $221,954—or nearly ten times as much—will be required for the multiple-purpose projects in the southwest. A gas-fired steam-electric station in the southwest, built for continuous operation will cost, at 1948 high prices, about $16,250 for each 1,000,000 kw-hr of primary energy, or only about one fourteenth of the cost of a multiple-purpose dam! Regardless of what may be done by allocating part of the cost of the dams to purposes other than power, and regardless of the difference in production cost between hydro and steam, it is evident that hydro plants in the southwest can be used effectively only if a peak load is carried exclusively. On the other hand, Columbia River power is suitable for base-load operations. Obviously, the coordination of power sources having such widely different characteristics cannot be realized by a single arbitrary formula. Each situation is different, and each problem must be solved by itself.

TABLE 5.—COMPARISON OF FEDERAL MULTIPLE-PURPOSE RESERVOIR PROJECTS IN THE COLUMBIA RIVER AREA WITH THOSE IN THE SOUTHWEST

Line	Description	Columbia Basin	Current Projects[a]	
			Quantities	%
1	Drainage area, in square miles	237,000	238,100	..
2	Ultimate installed capacity, in kilowatt-hours	2,200,000	1,566,000	71
3	Annual primary energy, in kilowatt-hours	12,255,000,000	2,333,600,000	19
4	Average annual energy, in kilowatt-hours	16,728,000,000	3,765,600,000	23
5	Estimated cost of projects, in dollars	291,858,872	517,951,000	177

[a] On the Red, Arkansas, White, and Ouachita rivers; values in the last column are percentages of the Columbia Basin quantities.

The principles that should govern each of these separate studies have been time tested and proved through many years of experience. Few utilities are self-sufficient in regard to power. Most of them are interconnected with neighbors and, in one way or another, participate in the pooled operation of the power resources of the area. During World War II, these power pools were very extensive in size. The one in the southwest, for example, comprised sixteen privately owned utilities and seven public power utilities. It extended from western Texas to central Mississippi, and from the Rio Grande to northern Nebraska. A total of eighty steam-electric stations (ranging from highly efficient base-load plants to old plants of the "teapot" variety), ninety-four internal combustion stations, and thirty-four hydroelectric stations (the largest of them equipped with reservoirs) was involved.

Each station was scheduled for operation day by day, and sometimes hour by hour. The place on the load curve assigned to each plant gave full recognition to its characteristics, capability, efficiency, and availability, and to the prevailing transmission limitations. The most efficient steam plants were placed on base load. The hydro plants were located on the load curve at the point where the available water would enable the maximum capacity possible to be realized. Then, one by one, the other steam and thermal plants were

added to the load in the order of their respective efficiencies, leaving the peak loads to be carried by the steam stations of poorest efficiencies, unless it proved best to pick off the peaks with the hydro plants. Steam units were scheduled for overhaul at the most suitable times; and, wherever possible, water was stored in the reservoirs of the hydro plants to be used at critical times, by substituting steam power for the hydro power and temporarily curtailing hydro operation.

To realize the best efficiency and to make the maximum effective use of each power resource, the operation of such a system cannot be allowed to become static. It must be flexible and subject to prompt adjustment to meet the constantly changing conditions.

The transmission system of such a coordinated operation is in reality an integral part of the power facilities, and should not be considered separately. Experience has shown that the most efficient and the least costly transmission system is one that fulfils several requirements. A well-designed network generally will:

1. Deliver power and energy to the various load centers;
2. Provide two-way service to all important points;
3. Interconnect and integrate the power resources;
4. Interconnect with neighboring utilities; and
5. Constitute an effective link in the regional power system.

When the Southwest Power Pool was formed during World War II, very little reinforcing was needed to enable the existing transmission systems to perform the necessary coordinating operations, and the job was done for a reasonable cost because the methods used were economically sound.

Although the power pools during the war dramatized the advantages to be gained by proper coordination between power resources, the principles had been developed and long been used by most of the power systems in the United States. These proved coordination methods, both in respect to generating plants and transmission lines, are precisely those needed to make the most effective use of the output of multiple-purpose dams. It is instructive, therefore, to review what has been done toward coordinating the output of the multiple-purpose dams already in service and what should be done about future dams. Should the coordination be by nationalization of the utility business, or by interaction with the taxpaying utilities that constitute a vital link in the American way of life?

To date, little if any real attempt has been made to plan, schedule, and operate multiple-purpose dams to fit the power requirements of the areas in which they are located. The federal government has confined its efforts to marketing such power, using the following two methods:

(*a*) Sales at powerhouse in wholesale quantities; and
(*b*) Establishment of regional authorities.

Selling power in wholesale lots at the powerhouse has been very successful for the most part. This plan was followed at the early Reclamation Service

dams and is used at Hoover Dam, where the available power is allocated among the distributors, public and private, who have built transmission lines to the powerhouse to take the power away. Although there is no evidence available that the use of Hoover Dam power has resulted in any savings to the distributors as compared with other available sources of power, this method of marketing the power output has proved quite favorable for the federal government and it has resulted in conserving fuel in a territory where cheap fuel no longer is obtainable in necessary amounts. Hoover Dam is one of the governmental projects that is "moneying out" as planned.

The outputs of the Morris Sheppard (Possum Kingdom) Dam in Texas, Denison Dam in Texas and Oklahoma, and Norfork Dam in Arkansas are all sold at or near the powerhouse.

The sales of the output of multiple-purpose dams at or near the powerhouse, and marketing of the power through the facilities of the existing utilities, have been proved successful, especially in respect to the financial returns to the government, and this practice minimizes the cost of energy to consumers. The method will be even more successful in the future if greater care is taken to design the multiple-purpose dams in cooperation with the experienced power people in the area so that the plants will:

(1) Be scheduled to come in service as needed;

(2) Be of a type, and be built on a schedule, that will permit complete coordination with existing power facilities; and

(3) Supply the power at a net cost at least no greater than the net cost of supplying equivalent power by other methods.

Even if "coordination" by force through nationalizing the electric utility industry were the most efficient way of doing the job, the by-products of this course, its long-range effects on the social and political structure are so undesirable, in the writer's opinion, that this method should be abandoned before more harm is done. In addition, the facts all point to this method as producing less efficient results than can be realized through coordination with the taxpaying utilities and the municipally owned utilities.

Experience in the Southwest

The writer is identified with a group of privately owned electric utilities which, collectively, compose an interconnected system that serves an area of some 114,000 sq miles in north-central Texas (the upper coastal plain) and sections of the state lying west and north of Dallas–Fort Worth, almost as far westward along the Texas Pacific Railroad as the Pecos River (see Fig. 12).

This territory shows wide variations in character as to: Elevation (Fig. 13(*a*)), topography, soils, climate, geological formation, rainfall (Fig. 13(*b*)), and natural resources. These varying characteristics naturally govern the economic and social status of the respective geographic divisions.

Referring to topographic and climatic features, the extreme western sections are in the southern end of the Great Plains, with elevations up to 3,000 ft and higher above the cap rock. On this Great Plains area, average rainfall varies from 10 in. to 20 in. The north and west escarpment of the coastal plain

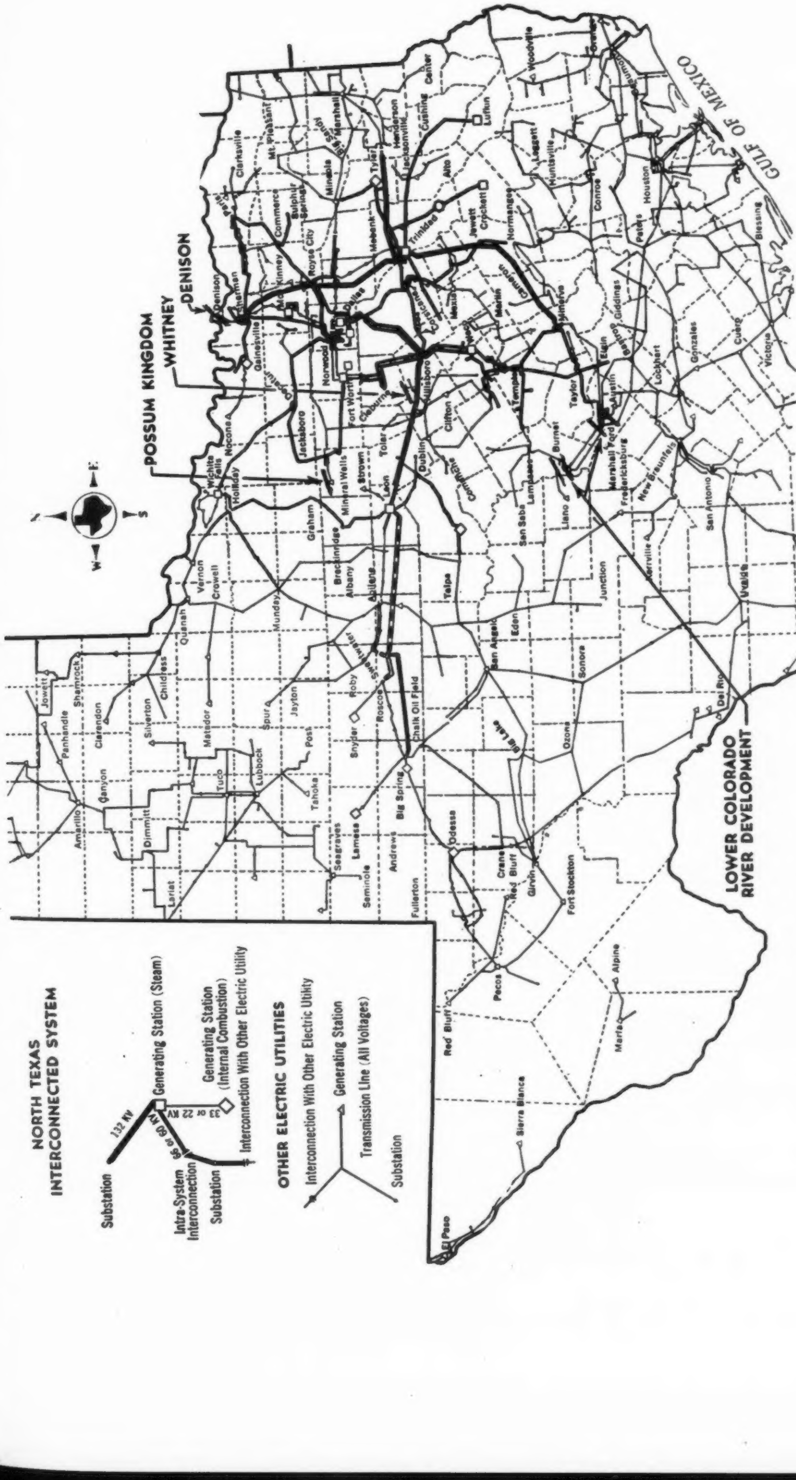


FIG. 12.—LOCATION OF NORTH TEXAS INTERCONNECTED SYSTEM AND OTHER ELECTRIC UTILITIES IN TEXAS

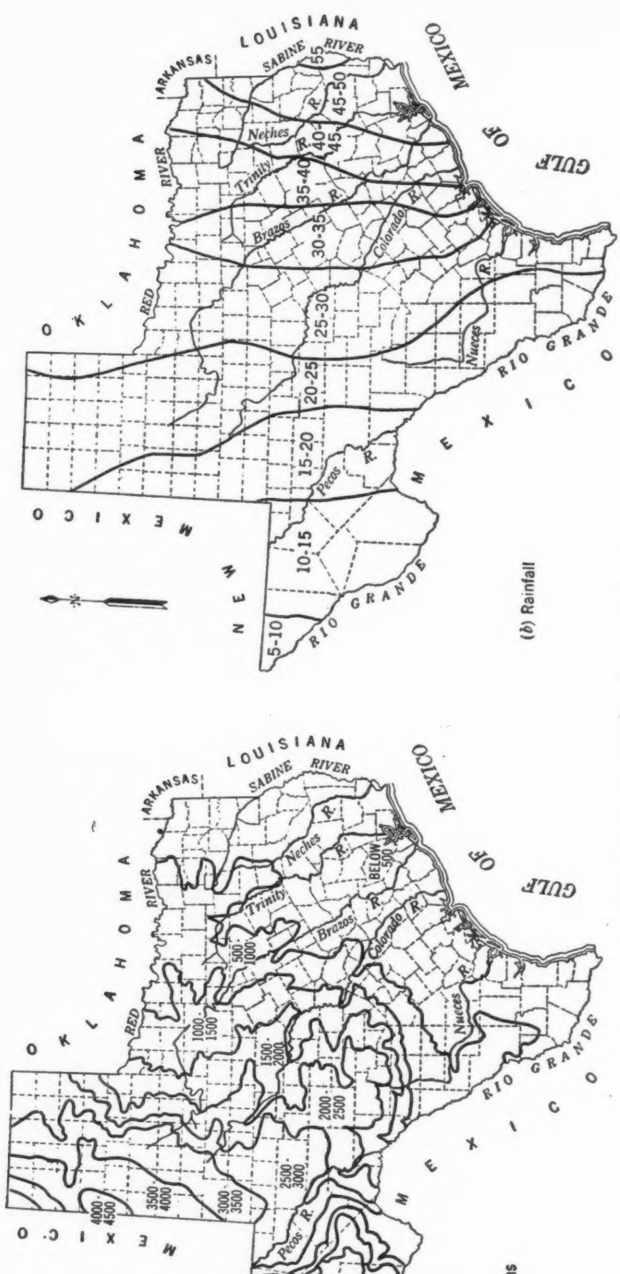


FIG. 13.—CHARACTERISTICS OF TEXAS AREAS

generally follows a line falling west of Fort Worth, through Austin and San Antonio. Between this escarpment and the upper plains country lies what is locally termed the hill country and the intermediate plains, having elevation extremes of from, say, 500 ft to 2,000 ft and a rainfall bracket of from 35 in. at Dallas to somewhat more than 20 in. at the western boundary.

Substantially all the hydroelectric projects fall within, or adjacent to, the service area of the utility companies with which the writer is identified; all the multiple-purpose reservoirs, existing or proposed in Texas, lie within this same region on rivers that flow from the upper plains or the hill country, southward, southeastward, or eastward to the coastal plains, and thence to the Gulf of Mexico.

The rivers rise in what would be classified as an arid region and, in general, are fed by rains that travel northward and westward from the Gulf region toward the headwaters of the rivers, following much the same course as the streams, but in reverse. As in most arid countries, the rainfall is highly variable and unpredictable; but, when excessive rainfall does occur, the result can be only the occurrence of extreme floods.

Numerous instances can be cited of unprecedented stages on the larger streams which, for the most part, were caused by floods on only one or a few of the tributaries. The greatest recorded flood on the Colorado River at Austin was contributed in the main by the Llano River. The largest recorded flow on the Brazos River below Cameron was caused mainly by rainfall on 4,000 sq miles, a minor part, of the Little River watershed.

The multiple-purpose reservoirs are in the hill country, at varying distances upstream from the coastal plain escarpment.

The Projects

The existing projects are described briefly in Table 6, with supplementary comment, as follows:

1. Denison Dam is on the Red River near Denison, on the boundary between Texas and Oklahoma (see Fig. 12). This project was constructed with federal funds by the Corps of Engineers and is operated by that organization, but marketing of the power is under the jurisdiction of the Southwestern Power Authority (an agency of the United States Department of the Interior).

Since this project was placed in operation in 1944, the Texas Power and Light Company has purchased all the power output under the terms of a temporary, wartime contract. In 1947, this company negotiated a new contract, under the terms of which it will utilize most of the capacity of the present 35,000-kw to 40,000-kw unit and will have the use of one half or more of the capacity of the third unit; the second unit is reserved for sales in the State of Oklahoma. A total of three units is proposed, the second of which was scheduled for completion around the end of 1948 but may not be in service before the middle of 1949.

2. The Morris Sheppard Dam on the Brazos River, approximately 18 miles northwest of Mineral Wells, Tex., comprises the first of a projected series of developments on the upper Brazos (above Waco) by the Brazos River Conservation and Reclamation District. This is an agency of the State of Texas

but it was assisted financially by the federal government in building the first unit in the plan.

The Whitney and several other sites of the multiple-purpose type are proposed to be developed, although the DeCordova Bend site would lend itself to little other than power purposes. Included in the grand scheme are some purely flood control reservoirs on the Leon River and other tributaries. These latter assume greater importance in the flood control plan than reservoirs on the main stream because the tributaries have developed record high unit-area runoffs.

TABLE 6.—DATA ON MULTIPLE-PURPOSE DAMS IN TEXAS, FROM VARIOUS SOURCES

Dam	Reservoir Storage, in Thousands of Acre-Feet				Capacity, in Thousands of Kilowatts		Energy, in Millions of Kilowatt-Hours	
	Total	Power	Flood control	Other	Installed	Firm	Primary	Average
(a) Red River								
Denison Dam near Denison, Tex.:								
Present (1948)	5,825.0[a]	1,148.0	2,745.0	1,932.0	40.0	28	140.0	218.0
Proposed (three units)	..	..	..	..	120.0	84	140.0	296.0
(b) Brazos River								
Possum Kingdom Dam, northwest of Mineral Wells, Tex.	730.0[b]	524.0	..[c]	206.0	22.5	10	24.0[d]	75.0
Whitney Dam, North of Waco, Tex.:								
Present (construction started in 1947; earthwork incomplete in 1948)	2,118.4[e]	131.7	1,731.4	..	..	..	33.2[f]	85.0[f]
Future	..	386.9	1,476.2	255.3	30.0[f]	23[f]	40.8[f]	98.1[f]
(c) Lower Colorado River Authority								
Austin Dam	1,950.0[a]	200.0[g]	590.0[h]	28.0	15.0[i]	..	..	..
Marshall Ford Dam	3,110.0	1,132.0	1,160.0[c]	..	75.0[i]	..	..	..
Inks Dam	1,100.0[a]	..	..	..	12.5[j]	..	..	..
Buchanan Dam	1,100.0	790.0	100.0[c]	210.0	25.0[i]	..	..	..
Total	..	..	..	..	125.0	116.0	200.0[k]	410.0[k]

[a] Below the spillway. [b] Total to top of gates. [c] Above the spillway. [d] This is the 1948 estimate, the preliminary estimate was 49,000,000 kw-hr and the estimate of the Federal Power Commission was 33,300,000 kw-hr. [e] Includes 100,900 acre-ft above the spillway. [f] Unofficial. [g] Used to store secondary energy; considered as an aid to flood control. [h] Controlled flood storage. [i] Units are kilovolt-amperes at 0.9 power factor. [j] Units are kilovolt-amperes at 0.95 power factor. [k] From a 1943 bond prospectus.

Flood control at Morris Sheppard Dam is provided by storage in the freeboard (maximum estimated height of flood crest above spillway).

The Brazos River Conservation and Reclamation District (the state agency operating the Brazos project) contracted to sell its entire output to the Brazos River Transmission Cooperative, Incorporated. The latter organization ex-

pected to market the output to the member cooperatives. Actually, the Texas Power and Light Company purchased the major part of the output from the Brazos River Transmission Cooperative and thus far has supplied the market for Morris Sheppard Dam output under terms of a wartime contract. The Texas Power and Light Company supplies the member cooperatives and makes the best possible use of the capacity and energy of the Morris Sheppard Dam.

During one year, the Texas Power and Light Company supplied more kilowatt-hours to the member cooperatives than it derived from Morris Sheppard Dam, although the aggregate peak demand of the Rural Electrification Administration (REA) probably did not exceed 2,000 kw. Future disposition of this power has not been resolved.

3. The Lower Colorado River Authority (LCRA) has developed a series of projects on the Colorado River and has two additional sites to be developed for power purposes, all upstream from the coastal plain escarpment at Austin.

The LCRA likewise is an agency of the State of Texas but was financially assisted by the federal government, having been advanced funds for the first construction project by a federal loan and grant. The loan was subsequently refinanced with bonds of the LCRA. The largest unit of the project, Marshall Ford Dam, was constructed with federal funds.

Power is marketed to many consumers directly; three of the private utilities purchase, under firm contracts, a total of 63,000 kw, the Texas Power and Light Company participating to the extent of 42,000 kw. The project cooperated fully with the wartime power program of the area.

Flood Control Characteristics

These several projects, as constructed and as proposed, are capable of considerable flood control. Perhaps it is superfluous to remark that anything short of proper operation of the facilities will deprive the public of the potential flood control benefits for which good money has been spent; conditions may even be aggravated.

The most ardent supporters of these Texas developments would not contend that the multiple-purpose projects, in themselves, are capable of controlling floods. Flood control is a compromise. Denison Dam will release all but extreme floods through turbines and sluiceways, capable of filling or probably overflowing the downstream channel; but it has been provided with a large, free discharge spillway. The Brazos River basins will have to be aided by several flood control reservoirs on the tributaries. Nevertheless, much is gained in utilizing the freeboard of uncontrolled spillways for flood control, the top storage in a reservoir frequently being the most economical unit-cost storage. The added flood control feature may bring economic justification that would be lacking on single-purpose power projects.

The writer does not propose to set himself up as an arbiter on the economic justification of the multiple-purpose dam projects that have been constructed in Texas, but he will state that—under his supervision and in some cases as long ago as 1927 when fuel prices were much higher and construction costs lower—comprehensive studies of Texas streams were made to determine

feasibility for development of hydro power. Without exception, the findings were unfavorable.

As to design and operation of electrical facilities, it appears that hydro power is economical in Texas because it offsets the high operating costs of thermal plants when operating at low load factors, or when operating as spinning reserve, in which case the amounts of hydro energy are small in proportion to the installed capacities. In general, the lower the load factor carried by hydro generation (within the limits of its relation in size to the load of the system on which it operates) the greater will be the economic justification for the hydro capacity, inasmuch as the trend of thermal plant unit production costs rises sharply with a reduced load factor. It follows that the peaks should always be carried by the hydro plant if the power pool storage is sufficient to provide the necessary flexibility.

Utilities in northern Texas have loads that are capable of absorbing to full advantage the hydroelectric capacity that thus far has been installed. Analyses have shown that a system of lesser size would not be capable of fully utilizing such hydro power—thus effectively illustrating the economic desirability of marketing low load factor hydro power to established power systems of ample size and load diversities, and of scheduling the new hydroelectric installations to conform with the ability of the power systems to absorb each new increment of hydro power.

The writer's philosophy as to proper design and operation may be delineated by presenting an analysis (see Fig. 14) of hydro power utilization that was prepared not so long ago, but based on 1940 loads. In this study, it was assumed that there would become available to the utilities in north Texas, from present and proposed projects on the Colorado, Brazos, and Red rivers, aggregate power equivalent to 130,500 kw, 178,400,000 kw-hr annually, and a 15.6% load factor.

Analyses were made which, summarized, showed the following tabulated results, which are illustrated by Fig. 14:

(*a*) In 1940, the Texas Power and Light Company (Fig. 14(*c*)) could have absorbed only 77,400 kw of the capacity although there was a peak demand of 125,410 kw;

(*b*) The load of the Texas Power and Light Company would have to increase to 216% of the 1940 load or to 270,890 kw to absorb the full 130,500 kw (Fig. 14 (*d*)); and

(*c*) The north Texas group of companies had a peak demand in 1940 of 282,950 kw (Fig. 14(*a*)); and the characteristics of the aggregate load were such that the upper 130,500 kw of the demand closely matched the 15.6% hydro power output.

Viewed from another angle, a 130,500-kw peak demand system (Fig. 14(*b*)), supplying a load having a 58% annual use factor, would have annual total energy requirements of 663,000,000 kw-hr, contrasted with the hydro yield of 178,400,000 kw-hr, or 26.9% of the required energy. At a 58% load factor the hydro could carry only a 35,000-kw load. Given a system supplied from

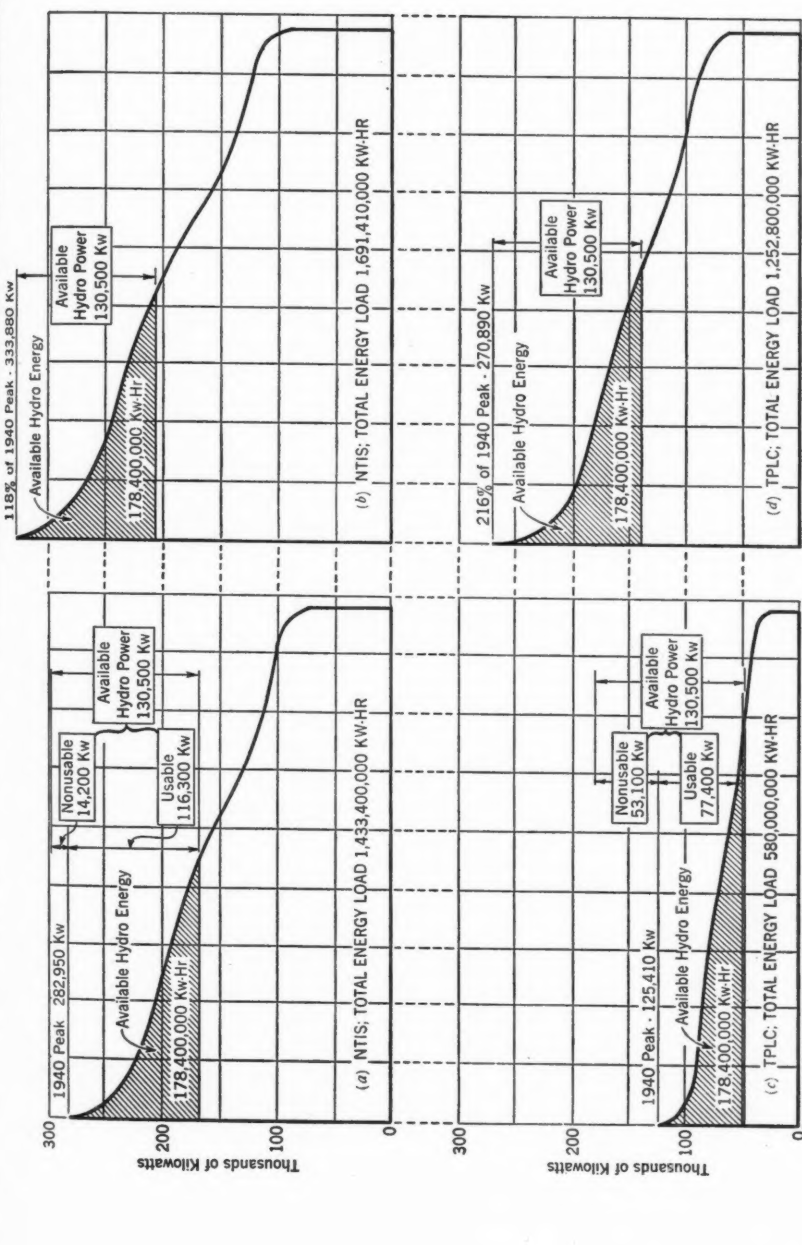


FIG. 14.—COMPARISON OF UTILIZATION OF HYDROELECTRIC POWER AND ENERGY, BY NORTH TEXAS INTERCONNECTED SYSTEM (NTIS) AND BY TEXAS POWER AND LIGHT COMPANY (TPLC)

thermal plants with a load of 333,880 kw, the total hydro capacity of 130,500 kw could be effectively used with the kilowatt-hours available.

The foregoing example and discussion cover basic facts that are well known to the power industry; they concern the "ABC's" of hydro power utilization. It is axiomatic that no commodity represents a bargain, at any price, unless there is a use for it, and hydro generation must fit the load pattern to be fully useful. The lower the load factor of generation (contrariwise, the greater the degree of capacity development), the greater must be the ratio of system peak load to the hydro capacity. This argument is increasingly true because utilization load factors have trended upward and have reached high annual totals, with almost unbelievably high seasonal and daily values. Hence, a low load factor power should not be constructed faster than the basic power system or systems can absorb it. It should be mentioned, in passing, that the determination of fitness is not so simple as in the illustrated case, utilizing a 1-yr load-duration curve. More accurate calculations require determinations by months, using monthly load-duration curves.

The mere fact that a system load can absorb the output of a hydro plant obviously does not, in itself, prove the economy of the hydro project. There are many factors that enter such an equation—for example, the existence of thermal capacity of lesser efficiency with which to carry peaks. However, it is almost a truism that hydro capacity has little, if any, economic justification unless its output can be substantially absorbed, because the unit investment in hydro capacity runs relatively high, except in a very few exceptional cases. On the other hand, hydro capacity, if wisely employed, offers advantages in addition to those commonly reflected in economic equations. Some of these are:

1. Hydro capacity may be added to the line quickly; in fact, it may be floated on the line as synchronous condenser capacity, ready for instant use, but with little cost or loss if the turbine gates are tight.

2. Under favorable conditions, energy may be stored during one season for use in another season; this storage is often justifiable in face of a risk of wasting some energy over the spillway.

3. Small hydroelectric projects, with a relatively low load factor, often may be utilized in reducing peaks imposed on the system by local or district loads (that is, geographical components of system peaks) with attendant reduction in losses, improved local voltage regulation, and perhaps yield of some worthwhile reserve capacity in the locality.

A revealing example of advantages 1 and 3 was the utilization of Morris Sheppard power during World War II. Although during 1944 when the hydro output was less than 12,000,000 kw-hr for the year the energy supplied the REA customers was greater than 12,000,000 kw-hr, the net "take" was in the red; yet Possum Kingdom Dam constituted a valuable aid in delivering power to war industries in the Dallas-Fort Worth area.

Illustrating advantage 2, during a period when additional energy was stored for the Texas Power and Light Company in the LCRA dams, the Texas Power and Light Company carried LCRA load at night by off-peak thermal

generation. The stored energy was used to stretch the daily load factor of hydro generation. There are many such devices that can be resorted to, and should be used, to derive optimum results.

The North Texas Interconnected System has thus far constituted, and most likely will constitute in the future, the only economical vehicle for the marketing of the hydro power in this territory.

Summary

Assuming that multiple-purpose dams are to be built for reclamation and flood control reasons (it being up to the public utility industry to make the best possible use of the power to be produced in order to be of the maximum feasible help to flood control and irrigation, and to make the burden on the taxpayers as light as possible), there is a proved course to follow which will realize the desired result in harmony with established business procedure. Such a course involves complete cooperation between the government bureaus that design and build the multiple-purpose dams, and the entire utility industry in each area in which the dams are located, so that:

a. The dams will be designed with a power output that fits in with the power resources of the area to the very best advantage;

b. The coordination is extended to include the existing transmission system, to avoid all unnecessary and wasteful duplication of facilities;

c. The rates for power and energy from multiple-purpose dams are equal to or less than the cost of producing equivalent power and energy by alternate available methods;

d. The cost to the taxpayer is kept at the lowest possible level; and

e. The experienced selling organization of the established utilities can market the additional power quickly to the greatest possible number of people.

Coordination in this manner will result in the maximum beneficial use of power and energy from multiple-purpose dams, the maximum return to the government on its investment, the lowest possible cost to the taxpayers, and the lowest rates to the users of electricity. In addition, it will benefit the causes of reclamation and flood control. Obviously, duplication and wasteful expenditures for power facilities mean less money for flood control and reclamation. Skill will be needed for the proper application of this solution to the problem, but it is abundantly available in the electric utility industry and the industry is willing and anxious to do its part in coordinating the output of the multiple-purpose dams with the other power resources of the United States.

INFLUENCE OF FEDERAL POWER COMMISSION ON DESIGN AND OPERATION

By E. Robert de Luccia,[14] M. ASCE

The influence of the Federal Power Commission on the design and operation of multiple-purpose reservoirs has probably been greater than the average engineer realizes. The Commission has broad responsibilities in connection with the improvement of those rivers under the jurisdiction of the United States, particularly as they relate to hydroelectric projects. In its work the Commission performs duties prescribed under the Federal Power Act with respect to the licensing of hydroelectric projects, and advises with other government agencies on river basin improvement programs. The commission is not engaged in actual construction work; nor does it operate any projects.

All the reservoir projects that the War Department has studied or constructed since the passage of the 1938 Flood Control Act, and about 350 projects, with a total of 5,600,000 kw of ultimate installed capacity, under license from the Commission since 1920 have been subject to the advice and consultation, or the approval, of the Commission before final designs and plans of operation have been adopted.

As an aid in understanding the influence of the Federal Power Commission on design and operation of multiple-purpose reservoirs, it will be helpful to review briefly a little of the history of the legislation relating to the conservation and development of rivers in the United States.

The authority of the United States to deal with the development of water power arises from the provisions of the Constitution with respect to interstate and foreign commerce and from its proprietary interest in public lands and reservations. The Act of June 6, 1866, confirmed rights of appropriation of waters for mining and provided for further acquisition of similar rights for "mining, agriculture, manufacturing and other purposes." Other acts modifying and amplifying the act of 1866 followed and, as a result of the initiation of hydroelectric developments in about 1890, the Act of May 4, 1896, was enacted to authorize the use of government lands for the generation of electric power. A number of subsequent acts amplified and supplemented the 1896 act, to include transmission lines among other matters.

During this period several acts were adopted for the protection of navigation by requiring certain permits to be obtained from the War Department with respect to the erection of structures in, or over, navigable waters. As a result of a multiplicity of acts, and the fact that new uses for water resources, such as the development of electric power, were becoming evident, attempts were made to give expression to the need for conserving water resources. Probably the first definite steps in the general conservation of water power resources were the reservation and the withdrawal from entry under the public land laws of government lands considered to have value for power purposes under the Act of June 25, 1910.

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[14] Chf., Bureau of Power, Federal Power Comm., Washington, D. C.

The growing consideration of the conservation of water power resources and the unsatisfactory conditions with respect to their protection and development under the then existing legislation kept the problem before Congress and resulted in the River and Harbor Appropriation Act of August 8, 1917. This act is of particular interest in that it established for the first time a commission with responsibilities for bringing into—

> "* * * cooperation and coordination the engineering, scientific and constructive services, bureaus, boards * * * that related to studies, development or control of waterways * * * with a view to uniting such services in investigating with respect to all watersheds of the United States questions relating to the development, improvement, regulation and control of navigation as a part of interstate and foreign commerce including therein the related questions of irrigation, drainage, water storage, control of floods, prevention of soil erosion, and utilization of water power."

Because of the start of World War I in 1917 that commission was never appointed.

In place of the 1917 act, the Federal Water Power Act was enacted by Congress on June 10, 1920, "to create a Federal Power Commission to be composed of the Secretaries of War, Interior and Agriculture." In 1930 the act was amended to provide for the independent five-man commission as it is generally known today. An important provision of the act of 1920 and which is related directly to the subject of this Symposium is Section 10(*a*) which provides that all licenses issued should be on the following conditions:

> "(*a*) That the project adopted, including the maps, plans, and specifications, shall be such as in the judgment of the Commission will be best adapted to a comprehensive scheme of improvement and utilization for the purposes of navigation, of water-power development, and of other beneficial public uses, and if necessary in order to secure such scheme the Commission shall have authority to require the modification of any project and of the plans and specifications of the project works before approval."

This section was amended in 1935 to include recreational purposes among "other beneficial public uses." The Flood Control Act of 1938 and the several flood control and river and harbor acts since that time require:

> "* * * that penstocks or other similar facilities adapted to possible future use in the development of hydroelectric power shall be installed in any dam herein authorized when approved by the Secretary of War upon the recommendation of the Chief of Engineers and the Federal Power Commission."

It is abundantly clear that it is the purpose of Congress that the water resources of the United States be conserved and that the development of the rivers of the nation shall include maximum provision for the use of waters for the development of hydroelectric power wherever feasible and consistent with other important uses.

The policy of the Federal Power Commission with respect to these matters is the policy of Congress as expressed in its many acts, and all measures and actions taken by the Commission with respect to its duties and responsibilities

relating to the rivers of the United States are in accordance with the statutory duties and responsibilities laid down in these acts.

Probably the best way of illustrating the policy of the Commission and its influence on the design and the operation of multiple-purpose reservoirs is to give a few examples of actual practice.

As an example of the work done with the War Department under the flood control and river and harbor acts, consider the Bull Shoals multiple-purpose project on the White River Basin in Arkansas. This project was included in a survey report of the Corps of Engineers transmitted to the Commission for review and comments in accordance with routine machinery which has been set up between the Corps of Engineers and the Commission. The project is immediately downstream from the existing privately-owned Ozark Beach hydroelectric plant which forms a reservoir known as Lake Taneycomo. In the survey report preliminary studies had placed the top of the flood control pool at the elevation of the tailwater of the Ozark Beach plant, and the maximum power pool at an elevation 83 ft lower which, of course, resulted in a loss of potential power head of that amount.

With a view to capturing all the head possible for development of power on the river at this location, the Commission's engineers determined that the dam should be raised and the power pool placed at about the elevation of Ozark Beach tailwater, with maximum water surface, under conditions of the reservoir design flood, at about the elevation of the spillway crest of the Ozark Beach Dam. Storage capacity allocated to flood control would not be lessened. Of course, there would be total loss of head and power at Ozark Beach under conditions of extreme flood. This situation occurs, however, under present conditions of maximum floods as the dam is relatively low. Also, if Ozark Beach is "drowned out" by Bull Shoals, maximum heads would obtain at the Bull Shoals power plant and generation there would be more than sufficient to compensate for the power lost at Ozark Beach.

By raising the Bull Shoals Dam about 42 ft, the maximum static head would be increased about 84 ft, the usable power storage increased about 10 times, the minimum regulated flow nearly doubled, the primary or continuous power nearly trebled, and the average annual generation about doubled. Such improvements in the power at this project were well worth the effort.

These matters were discussed most thoroughly with the Corps of Engineers, joint visits were made to the site; full consideration was given to the adverse effects from inundations; and costs, power markets, and power values were studied. After thorough investigation, the Corps of Engineers adopted substantially the suggestions of the Commission's staff, and greater benefits will be obtained.

Another example of the influence of the Commission is illustrated by the studies relating to the development of the Alabama-Coosa River. This stream flows from the headwater mountain streams in northwestern Georgia south through the length of the State of Alabama to Mobile Bay after it has joined with the Tombigbee River a few miles north of Mobile.

In 1941, the Chief of Engineers requested the Commission's comments on a comprehensive report of the district and division engineers on the Alabama-

Coosa River, in which about twenty-five projects had been recommended for the control of the river for the purposes of navigation and development of hydroelectric power. The plan of development outlined in the report included several small tributary reservoirs and a complete chain of dams on the main stem of the river from Rome, Ga., to the mouth of the Alabama River. Slack-water navigation was to be provided by a system of locks at proposed and existing dams, with power to be developed at those dams which were sufficiently high to warrant power installation. The generation of power at existing power projects on the river averages about 2,000,000,000 kw-hr per yr, and the prospective development suggested in the report would result in the generation of an additional 1,000,000,000 kw-hr.

In response to the request of the Chief of Engineers, the Commission in June, 1941, forwarded the results of a preliminary study, by the Commission staff, of the proposed waterway project and suggested that the plan be modified to include fewer but higher navigation dams and rearrangements of power installations. With these modifications and other changes to effect the full coordinated operation of the entire system of projects, the Commission staff found that the additional generation on the river could be increased from 1,000,000,000 kw-hr to 2,000,000,000 kw-hr.

The Chief of Engineers stated in his reply that the Board of Engineers for Rivers and Harbors was substantially in accord with the views of the Commission and that revision of the report appeared desirable. Additional studies were then undertaken by the Corps of Engineers, in cooperation with the Commission's engineers, resulting in plans for the comprehensive development of the river. In addition to other water use purposes, this development will make possible an ultimate generation on the river greatly in excess of even that indicated in the preliminary studies by the Commission. The authorization for the Alabama-Coosa development was included in the 1945 river and harbor act which in specific language envisages this greater generation of power found feasible by the later studies.

As part of its duties the Commission is required to assure itself as to the safety and adequacy of the dams, powerhouses, and appurtenant works which it licenses. In discharging these duties, the Commission frequently requires major structural revisions in design. These revisions cover such items as increasing spillway capacity, providing greater freeboard for wave action, prescribing different or more complete foundation treatment, changes in detail design items relating to size and number of reinforcing bars, strength to concrete, suitability of aggregates, and many others. Sometimes the Commission finds that a higher dam and an increased installed capacity are required so that the project will be best adapted to a comprehensive scheme of development.

An example of this phase of the Commission's work is illustrated by the Saluda Dam of the South Carolina Electric and Gas Company, Federal Power Commission licensed project No. 516. This project is located on the Saluda River about 18 miles above Columbia, S. C., and consists of a semihydraulic earth fill structure about 212 ft high and about 7,900 ft long, a large reservoir, known as Lake Murray, 30 miles long with about 2,500,000 acre-ft of storage capacity, and a powerhouse with an installed capacity of 135,000 kw.

The Commission's staff was at one time concerned over the stability of the dam and the adequacy of the spillway. Passage of the floods of 1929 and 1936 indicated inadequate spillway capacity. After the 1936 flood the downstream part of the dam became saturated. The Commission, therefore, ordered that the operating level of the reservoir be lowered and required that settlement readings and water level records be taken within the downstream face of the dam and that corrective measures be adopted to assure the safety of the dam.

A plan of remedial action was agreed on and approved by the Commission providing for raising the dam 3 ft to restore design grade. Thus the spillway capacity was increased by about 140%, and the stability of the dam was improved by flattening the downstream slope. Approximately 1,000,000 cu yd of earth fill and rock fill was placed on the downstream face of the dam. As a result of these improvements the licensee has been permitted to increase the normal water surface elevation of the reservoir from 355 ft to 360 ft.

Another example is found in the Wilder Development, of the Bellows Falls Power Company, on the Connecticut River in New Hampshire and Vermont, which was not constructed under license, but which was later brought under license. The project consists of a dam 30 ft high, a small pond, and two powerhouses with turbine capacity of 5,400 kw operating under a head of about 36 ft. Studies made by the staff of the Commission indicated that the existing project did not make maximum use of the project site. With increased capacity greater flow would be available and a higher dam would be best adapted to a comprehensive plan for river development. Provision was made in a license issued April 22, 1944, for the redevelopment of the project in accordance with such plans as would be found by the Commission to conform best to a comprehensive plan for improving and developing the Connecticut River, for the use and the benefit of interstate commerce, for the improvement and the utilization of water power development, and for other beneficial public uses, including recreational purposes. The licensee is now (1949) redeveloping the project by constructing a new dam about three quarters of a mile downstream from existing Wilder Dam with the pond level about 16 ft higher than present level and a new powerhouse with installed capacity of 33,000 kw operating under a head of about 51 ft.

In 1923, the Commission issued a license for a project on the Ouachita River in Arkansas to the Arkansas Power and Light Company. The company's plans were approved with the requirement pursuant to Section 10(*a*) of the act with respect to proper and comprehensive development of reservoir sites for production of hydroelectric power and other beneficial public uses, that further studies be made for a larger development to permit full utilization of the site and the water resources for power, navigation, and flood control. The Flood Control Act of 1938 authorized the War Department to participate in an amount not to exceed $2,000,000 in the construction of a multiple-purpose reservoir, at the Blakely site, this participation was to have been with the power company in the interests of navigation and flood control. However, the company's plans for commencement of construction were indefinite and the Flood Control Act of 1944 authorized construction of the entire project by the Corps of Engineers.

To summarize briefly, the Federal Power Commission's influence on the design and the operation of multiple-purpose reservoirs results from its work in the licensing of hydroelectric projects and its studies of river basins since 1920 under the Federal Power Act, its duties under the flood control and river and harbor acts since 1938, and, more recently, its active participation in the cooperative work done under the Federal Inter Agency Agreement procedure.

The basic contributions of the Commission have resulted in making engineers realize that one project is only a unit of a whole series of projects in an entire river basin; and that the operation of multiple-purpose projects can be so arranged, after appropriate methods are included in the design stage, to increase greatly the power yields of a stream without in any way impairing the use of the stream for other primary purposes such as irrigation, flood control, navigation, and domestic uses.

THEIR RELATION TO FISH AND WILDLIFE

BY RUDOLPH DIEFFENBACH[15]

INTRODUCTION

Until recently, few dams could claim to have "multiple purposes" in the present accepted meaning of the term; that is, they were not designed to make complete economic use of every available unit of water, fall, or land. In the past few years, a great movement has begun to develop practically every important river basin in the land, with emphasis on flood control, irrigation, power, navigation, water supply, and silt control. Congress has recognized that the fish and wildlife resources affected by the dams are worth millions of dollars, and has strengthened the laws that give to the Fish and Wildlife Service, U. S. Department of the Interior, the responsibility for conserving these resources. This federal agency was formed in 1940 by consolidation of the former bureaus of Fisheries and of Biological Survey, which had been established in 1871 and 1885, respectively. Under the new status, the service is rapidly formulating policies and building up the machinery necessary to make them effective. It is the purpose of this paper to define these policies and to explain their underlying purposes.

BASIC PRINCIPLES

The Fish and Wildlife Service assumes that full development of a multiple-purpose project can be achieved only if all its resources are taken into account in the plans for development. Not only should plans be devised to preserve existing resources wherever possible, but every feasible procedure for increasing them should be adopted. These public values will afford great benefits to the people and proper use of water is essential to their perpetuation.

It is conservatively estimated that not less than 20,000,000 people in the United States annually indulge in the sports of hunting and fishing, thus obtaining food and healthful recreation in forests and fields, and on lakes and streams. Each year these people spend about $2,000,000,000 for equipment, guide fees, transportation, and related items. Much of this money goes into local communities and small industries. A small part supports state and federal agencies charged with the responsibility for perpetuating the supply of fish, birds, and game animals. The food value of noncommercial fish and game annually taken exceeds $500,000,000. After World War I, hunting and fishing pressure immediately increased 30%. Statistics today indicate that there will be not less than a 40% increase in hunting and fishing pressure, with the strong likelihood that the increase will be 50% or more. Viewing this situation from the economic side alone, hunting and fishing must be classified as big business.

It is unfortunate that, in the past, many reservoir projects have been planned, constructed, and operated without consideration of the interests of

[15] Coordinator, River Basin Studies, Fish and Wildlife Service, U. S. Dept. of the Interior, Washington, D. C.

fish and wildlife. To permit the maximum development of river basins, this policy is being replaced by a more rational view of all natural resources. Reservoirs should be planned to serve multiple purposes, including fish and wildlife. Such plans will involve, in many cases, additional expenditures for structures and operation, but the investments will pay dividends throughout the life of the projects.

Law Putting New Policy Into Effect

To implement this more enlightened concept Congress enacted Public Law No. 732 (House of Representatives Bill No. 6097), approved on August 14, 1946, to amend the Act of March 19, 1934, entitled, "An Act to promote the conservation of wildlife, fish and game, and for other purposes." The new law is referred to as the revised "Coordination Act." Its scope is illustrated by the following extracts:

> "Whenever the waters of any stream or other body of water are authorized to be impounded, diverted, or otherwise controlled for any purpose whatever by any department or agency of the United States, or by any public or private agency under Federal permit, such department or agency first shall consult with the Fish and Wildlife Service and the head of the agency exercising administration over the wildlife resources of the State wherein the impoundment, diversion, or other control facility is to be constructed with a view to preventing loss of and damage to wildlife resources, and the reports and recommendations of the Secretary of the Interior and of the head of the agency exercising administration over the wildlife resources of the State * * * shall be made an integral part of any report submitted by any agency of the Federal Government responsible for engineering surveys and construction of such projects.
>
> "The cost of planning for and the construction or installation and maintenance of any such means and measures shall be included in and shall constitute an integral part of the costs of such projects: * * * In the case of construction by a Federal agency, that agency is authorized to transfer, out of appropriations or other funds made available for surveying, engineering, or construction to the Fish and Wildlife Service, such funds as may be necessary to conduct the investigations required. * * *
>
> "Whenever the waters of any stream or other body of water are impounded * * * adequate provision consistent with the primary purposes of such impoundment * * * shall be made for the use thereof, together with any areas of land, or interest therein, acquired or administered in connection therewith, for the conservation, maintenance, and management of wildlife, resources thereof, and its habitat thereon. * * *
>
> "The provisions of this Act shall not apply to the Tennessee Valley Authority."

A thorough study of the "Coordination Act" by all engineers who are interested in multiple-purpose dams is suggested. The foregoing quotations merely touch the highlights sufficiently to indicate that the policies expressed by this act give a definite measure of responsibility to the Fish and Wildlife Service to take a constructive part in planning the multiple-purpose use of reservoirs. Previous laws had no such force, but the Flood Control Act of 1944 did enable the Service to set up a special staff to make studies of, and reports on, river basins.

River Basin Studies

A river basin study may involve surveys, investigations, and reports on a single reservoir, on a group of projects, or even on all the projects in coordinated plans for an entire river basin. It is to be hoped that eventually every project may be studied in the light of the effects on the fish and wildlife of an entire river basin, as well as on those of the immediate locality, since a single project near a basin headwater may conceivably affect the entire valley down to the mouth of the main river. In fulfilling the intent of the "Coordination Act," a study usually embraces the following procedure:

1. A through examination of the project as outlined by the sponsor, to gain a complete understanding of the engineering plans and proposed methods of operation;
2. A biological field survey, including mapping of vegetational types on the affected areas, to determine the present quantity of fish and wildlife and their habitats;
3. The collection and study of all available fish and wildlife statistics applicable to the vicinity (in conjunction with state agencies);
4. An investigation of the effect of the project on fish and wildlife after completion (based largely on knowledge of the history of other developments);
5. An estimation of the present and future dollar value of fish and wildlife on the area, and determination of the net value;
6. The formulation of suggestions for modifying plans and methods of construction and operation which would prevent unnecessary losses and insure maximum gains to fish and wildlife—the more common recommendations in such reports being concerned with stabilization of water levels, maintenance of a permanent pool, maintenance of minimum flow below reservoir, fish protective devices, food and cover planting, wildlife management areas, and public access; and
7. The preparation of a concise, understandable report which will embody all the foregoing steps.

The most difficult part of this program is step 5, the determination of dollar values for fish and game. The need for such a valuation becomes evident in view of the fact that the river developments planned by the Corps of Engineers and the Bureau of Reclamation are measured in terms of money. These projects stand or fall after having been measured by this yardstick. Therefore, in order that the findings of the Fish and Wildlife Service may be expressed in terms understandable to the sponsors of the projects and to the Congress of the United States, the Service must also convert fish and wildlife values into monetary terms.

Although the methods employed to determine the money values of fish and game, which seem basically sound, have been accepted widely by conservationists, the Service is constantly seeking improvement. In particular, assurance is needed that adequate consideration is given to the esthetic values associated with these resources. All esthetic values cannot be reduced to dollars and cents, but their importance should not be underestimated for "man does not live by bread alone."

Part Played by Engineers

The hydraulic engineer has a definite place in the river basin studies organization. This group does not presume to pass judgment on plans prepared by the sponsor, but since the plans are couched in engineering language they often require reduction to terms and measures that the biologist cannot mistake. Therefore, an effort is made to include in every unit of the organization an engineer capable of interpreting this language to the biologist. The engineer also defines the limits of the recommendations by the Service affecting changes in engineering plans with the view to keeping them reasonable. In fact, the Service is developing a new type of technician, who might be called a "biological engineer," with a working knowledge of biology grafted onto a training in hydraulics.

Alterations in Dam Design and Operation

Studies have indicated that both fish and wildlife are more likely to be affected by the methods of hydraulic operation than by the type of dam. There are occasions, however, when it appears desirable to make certain alterations or additions to the primary design. For instance, normal engineering plans may provide outlets at only one level; but, because of the tendency of water to stratify into layers of different temperatures and chemical characteristics, there may be a distinct advantage in drawing off water at other levels during certain times of the year. Obviously, such a situation calls for the addition of several outlets, at various elevations between the bottom and the top of the dam.

Where the stream under investigation is used by great numbers of migratory fish, such as the salmon, the addition of fishways over the dam may be necessary, as only thus can the fish make their periodic spawning migrations to the headwaters. On the other hand, the addition of gate screens on dam outlets may be desirable, to prevent the downstream escape of fish from the reservoir.

Hydraulic operation of a dam may affect fish and wildlife favorably or unfavorably, depending on the resultant fluctuations in the reservoir and in the rivers downstream. The following examples will illustrate the point:

The value of a reservoir for fish and wildlife depends largely on the mode of operation. It is deplorable that the needs of irrigation, power, and flood control usually demand large fluctuations in reservoir levels and discharges, as such changes are commonly in direct conflict with the needs of fish and wildlife. Extreme or rapid changes in pool stages and stream discharges tend to disturb biological conditions, and thereby impose severe limitations on the productive capacity of most aquatic animals. Uniform levels in reservoirs are not expected, but the Service frequently recommends that fluctuations be limited during biologically critical periods, such as during the spawning of fish and the rapid growth of plants.

To offset losses from a widely fluctuating reservoir, the Service may recommend subimpoundments in the shallow arms of a reservoir. These are partitions by low dams constructed to maintain controlled water levels. Such ponds

create valuable fish spawning areas, feeding grounds for waterfowl, and breeding places for muskrats and other fur animals.

When water is released to the stream below in a manner calculated to eliminate or to reduce flood peaks and to provide a steady minimum flow of sufficient volume, it is reasonable to expect an increase in fish and wildlife values. The complete cutting off of flow, even for short periods, might be disastrous, since the entire fish population would probably be destroyed.

Actual examples of all the aforementioned conditions may be found in existing projects all over the Unites States. One great reservoir is filled and practically emptied yearly, with the result that a marginal mudbank is formed a mile or more in width, with practically no plant growth, and the pool is almost a biological desert. In contrast, there is another large project where operation is such as to minimize fluctuations of pool levels. There the mudbank is missing, the reservoir is teeming with fish, and waterfowl are multiplying.

Reservoirs that inundate wooded bottom lands destroy one of the most valuable of all habitats for wildlife and eliminate important areas for waterfowl and fur animals. In addition, vital winter cover, on which game of a wide area is dependent, may be destroyed. For example, proposed reservoirs on the Missouri River, if constructed, will extend almost the entire width of South Dakota. They will cause the elimination of winter cover essential for deer, and will cause substantial losses to pheasant and sharp-tailed grouse production. In an attempt to replace these losses of cover, planting recommendations are made. It is hoped that these will be at least partly adequate.

In gathering data for a river basin study involving a multiple-purpose dam, among the most important items required of the sponsor are operation graphs of proposed pool and stream fluctuations. These graphs (which should cover as many years as available stream flow records will permit) are studied to ascertain the probable future effect of operation on fish and wildlife. Where the effect is deemed injurious, suggested changes in operation are made to reduce the harm or perhaps even to bring benefits. The Service is keenly aware, however, of the fact that a single change in an operating schedule may dislocate an entire program. Therefore, suggestions for changes are made with great caution and with the understanding that they may not be adopted if inconsistent with the primary purposes of the project.

Conclusions

The Fish and Wildlife Service is convinced that the industrial development of all river basins should be realized, but not to the exclusion, or at the expense, of other aspects of regional wealth. If the plans for development too lightly consider the bountiful fish and wildlife resources found in streams, valleys, hills, and plains, resources of great economic importance and priceless esthetic value will be lost forever. The Service is optimistic in its belief that, by cooperation between governmental agencies, by intelligent planning, and by careful management, the present fish and wildlife resources can be not only preserved in large part, but in many areas actually improved.

PLANNING FOR THE RECREATIONAL USE OF RESERVOIRS

BY CONRAD L. WIRTH[16]

Since about 1946 there has been a great outpouring of literature in regard to the various proposals advanced for the control of water resources in the United States, particularly west of the Mississippi River where the problem is not only to prevent floods and to provide for navigation, but also to conserve water for agriculture, power, and other uses. Periodicals—popular, professional, and organizational—have carried articles dealing with one or more phases of the subject. Hundreds of studies have been made by interested agencies and many of the results have been published. Cartoonists and cartographers have found a fertile field for their skills. Organizations have been formed to put forward ideas in behalf of one proposal or against another. All this serves to demonstrate the interest, or concern, in the subject of water conservation.

The National Park Service, U. S. Department of the Interior, shares both interest and concern—interest, because of the inherent possibilities for the extension of recreational opportunities, and concern because of the possibilities of injurious effects on national or state park areas. To explain these attitudes, it is necessary to outline some of the background of the Service as regards protecting such areas from abuse or unwarranted intrusion, and fostering the provision of opportunities for outdoor recreation in natural surroundings. Under Congressional mandate, the National Park Service protects and administers the 168 areas of the National Park System—

> "* * * to conserve the scenery and the natural and historic objects and the wild life * * * and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."

It is evident from this definition that the Service would be vitally concerned with any proposal which might result in major changes to, or the inundation of, the lakes or streams in a national park since the natural conditions would be seriously altered in either case. The Service cannot tolerate such alterations. Furthermore, there are many scenic and recreational values that would be adversely affected by reservoir construction. The destruction of scenic, scientific, and cultural features can be of serious import when balancing benefits gained against benefits lost. The same is true of the destruction of fishing waters, a fact which is constantly being emphasized by the Fish and Wildlife Service and the Izaak Walton League.

The preservation of historic and archeological sites and remains is an important function of the Service. To assist in discharging this responsibility, provisions of the Historic Sites Act of 1935 include authority to make necessary surveys to determine those prehistoric and historic resources which are entitled

[16] Chf. of Land and Recreational Planning, National Park Service, U. S. Dept. of the Interior, Washington, D. C.

to federal, state, or local protection. Since the routes of travel and habitats of man throughout the ages have been in the river valleys, it is easy to understand the urgency of preserving or salvaging any remains or artifacts that may help to interpret earlier American culture and that are in danger of being lost forever with the rise of the reservoir waters. Therefore, historians and archeologists of the National Park Service and archeologists of the Smithsonian Institution under a cooperative agreement are diligently studying the areas to be inundated in an attempt to salvage valuable source material.

Under authority of the Park, Parkway, and Recreational Area Study Act of 1936, the National Park Service cooperates with other federal and state agencies in solving park and recreation problems. This act made official a relationship that had developed in a limited manner since the inception of the National Park Service in 1916. Its greatest impetus was gained with the creation of the Civilian Conservation Corps and the emergency relief program, when for the first time federal funds were made available to assist in the development of state parks and related areas. The Service guided these programs, in many instances aiding in the establishment of park systems where none existed before, and, pursuant to the aforementioned act of 1936, cooperated with forty six of the states and the Territory of Hawaii in conducting state-wide recreation surveys. It quite naturally follows that the Service considers that it should be alert to assist in averting, if possible, any threat to the park areas of the states or of their political subdivisions which might arise from proposed inundations.

The interest of the National Park Service in the field of recreation, therefore, is much broader than mere concern with the areas under its administration. As reservoirs are brought into existence, some new recreational opportunities usually are created. A public, increasingly vigilant for more opportunities to use leisure time, demands that these areas be put at its disposal. Although not indispensable, bodies of water greatly enhance and stimulate outdoor recreation, particularly in the more arid sections of the United States, and this fact has been recognized in the establishment of the various state park systems. These systems, however, have seldom been developed to the point where all recreational needs of the region are met. Consequently, impounding water for other reasons usually necessitates studies of the recreational potentialities of the area involved and the requirements of the population within a reasonable travel distance.

Recognition of the recreational advantages to be gained incident to reservoir construction is almost universally granted by writers of papers concerning the accelerated water control programs, and the Flood Control Act of 1944 specifically mentions authority for the provision of recreation areas and facilities. Pursuant to this act and under agreements with the Bureau of Reclamation and the Corps of Engineers, the National Park Service, using the powers granted by the Park, Parkway, and Recreational Area Study Act of 1936, investigates the recreational resources of reservoir sites and makes recommendations for their protection, development, and use. Such activity is initiated only on the request of the particular agency concerned. After necessary field studies have been made, a report to the agency is compiled in

which the Service identifies, appraises, and evaluates the scenic, scientific, historical, and archeological features and recreational potentialities, and recommends appropriate preservation and development. In this report it is important to note that existing and proposed recreational developments, plans, and programs of other agencies and estimated recreational needs are taken into consideration. Basin-wide consideration of all recreational resources is essential so that federal, state, and local agencies will work together in achieving a coordinated and integrated system of areas, facilities, and programs. Only thus can wasteful and irrational overlapping be avoided while, at the same time, recreational opportunities are provided as equitably as possible for all the people of the basin.

After it is decided that a proposed reservoir will offer needed advantages for recreation, the question immediately arises as to what agency should properly be the one to assume responsibility for operation of the area and facilities when provided. This question is settled on the basis of its comparative importance and the ability and willingness of the appropriate agency or agencies to assume the obligation. In some few cases, such as the Boulder Canyon and Grand Coulee projects, where the recreational resources are of more than regional significance, the National Park Service, by request, is undertaking administration of the recreational aspects of the areas under cooperative agreements with the agency having primary jurisdiction over the reservoir area. In other cases, where reservoir developments may be located partly or entirely on lands of other federal agencies, these agencies might properly administer the areas. In general, however, reservoir sites are largely of state or local interest, and responsibility for management of recreational developments logically falls on the appropriate state or local agency. It is evident that, where only a few picnic tables are indicated, for instance, the community which will use these facilities should be expected to take care of them. An area for which a more ambitious program of development is planned and which presumably would draw visitors from various parts of the state should be maintained and operated by funds derived from the state at large. Where the dam site is accessible by automobile, there is likely to be an influx of visitors drawn to the location by curiosity during the construction period and later by interest in operation, particularly where power is generated. Provisions for the care and convenience of such visitors should be the responsibility of the primary operating agency.

As to the procedure involved in the cooperative work on river basin recreation surveys, it is basic that agreements must be consummated and funds provided. Except for the Missouri River Basin, funds are made available by an appropriation specifically for "River Basin Studies." The Missouri River Basin work, however, is financed by an allotment from the Bureau of Reclamation from funds available for the purpose, as a part of the departmental program for the basin. The National Park Service in turn reallots funds to the Smithsonian Institution for the conduct of archeological investigations and preliminary archeological salvage under the terms of an interbureau agreement.

With the necessary agreements executed and the equally important matter of funds attended to, the Service is ready to begin the studies which lead to con-

clusions and recommendations as to what recreational developments, if any, are considered desirable. The field work is directed from one of the four regional offices maintained by the Service. Whenever a basin-wide survey in cooperation with the Bureau of Reclamation has been provided, a staff is set up in the regional office concerned, or elsewhere, under the immediate direction of a chief of that particular survey. Actual field studies are then initiated for designated reservoir sites according to established priorities. After considering topography, natural advantages of cover or scenery, historical or other scientific interests, population distribution, accessibility, and any existing or proposed neighboring recreation areas, the various factors are weighed and a determination is reached as to whether the site under investigation has recreational possibilities that warrant development and, if so, to what extent. A preliminary report is then submitted to the Bureau of Reclamation. Reservoir sites are similarly investigated on request of the district engineers of the Corps of Engineers; but, except for occasional consulting assistance in plan preparation, the resulting reconnaissance or preliminary report is all that is expected of the Service since planning personnel are available in the district offices of the Corps of Engineers.

Because the Bureau of Reclamation has no professional personnel to plan for recreational developments, cooperative agreements are extended to cover more comprehensive studies and the actual planning of the recreational areas and attendant facilities. If desired, the Service may also furnish technical advice and supervision during construction stages. As may readily be suspected, landscape architects, architects, engineers, historians, archeologists, foresters, biologists, and geologists must be used to explore all phases and to plan for the complex developments necessary to accommodate an area to intensive human use. Since the National Park Service has long been engaged in similar or related work, the organization of such a force requires only an expansion of personnel. The application of long-familar principles then produces the desired results. As stated in another paper of this Symposium, the Fish and Wildlife Service of the U. S. Department of the Interior investigates the fish and wildlife aspects.

Although the evaluation of recreational benefits in monetary terms is difficult and unsatisfactory because of such variables as the intangibles involved and the lack of data, the Service is often called on to attempt such evaluations. This work is undertaken reluctantly and with the full knowledge of all concerned that the evaluations are only estimates. However, until more is known about this subject, any estimates prepared will be scrupulously conservative. These evaluations are required principally by the Bureau of Reclamation. The attitude of the Corps of Engineers is less sanguine, as evidenced from this quotation from *Circular Letter No. 4231:*

> "In many cases the most important benefits from the recreational use of a reservoir area cannot be evaluated satisfactorily on a monetary basis, and it is not necessary in most cases that a monetary value be determined. These important benefits should nevertheless be fully described and discussed in the report. If desirable, an approximate or partial monetary evaluation of the recreational benefits may be included as a means to indicate their magnitude."

The Missouri River Basin program is further advanced at this date (1949) than are similar programs for other river basins, and it is interesting to note that coordination has been the keystone to progress of the work. The interrelations of the many responsibilities of diverse agencies have been recognized by the formation of federal inter agency committees, both in the field and in Washington, D. C., and by the establishment of a departmental field committee for the U. S. Department of the Interior. Thus, the duplication and the overlapping that might otherwise be encountered are avoided, and, at the same time, all phases of the vast problem of planning for the control of the water resources of a great river basin receive attention. It is expected that programs for other river basins will be coordinated in a similar manner.

It may fairly be asked whether there is any sound basis for assuming that the considerable expense involved in the creation of so many new recreational facilities is warranted. The answer may be found in several directions. Cooperative studies under the Park, Parkway and Recreational Area Study Act resulted in completed reports in thirty-seven states in which the present situation and the deficiencies were described. It became apparent immediately that there are large segments of the population which either are not served by any area within reasonable travel distance, or are inadequately served. Attendance records or trends also give indications as to the need for expanded opportunities. The total attendance for the last prewar year at state parks and related types of recreational areas approximated 90,000,000. Estimates based on the curve for preceding years indicate that provision of adequate facilities and programs will attract an attendance of at least 200,000,000 by 1960. Present accommodations would fall far short of meeting this demand. It should also be borne in mind that the ardent fisherman is certain to wet his hook in any body of water that is home to a fish. Many new reservoirs provide excellent fishing and therefore draw anglers from considerable distances as well as from the immediate vicinity. This interest dictates the provision of facilities for boating, fishing supplies, and, in many cases, overnight accommodations where fishing is good regardless of the possible proximity of other recreation areas.

A hint has been given of the economic aspects of park and outdoor recreation. The subject could be considered at much greater length if space were adequate. It could be shown that many and varied forms of occupations and business enterprises are provided by the use of recreational facilities. Data could be produced putting recreation in the big business class with total annual expenditures running into billions of dollars. It is not at all absurd to argue that outdoor recreation has an economic influence in the health-giving effect of rest and relaxation—intangible, to be sure, but none the less real and important. The National Park Service feels that it has a contribution to make to the economy of the United States by its participation in the development of new recreational areas where they are justified.

A social significance is attached to the development and the use of parks and related recreational areas. It is natural and desirable that citizens who are pent up in the cities and industrial centers should seek release and relaxation

in the open air on their holidays. The need for contact with nature is strong within nearly everyone. Although perhaps subconscious, the feeling is there, and its satisfaction is important to a well-rounded, normal existence. The individual who craves hikes or reveries in solitude, the family that picnics on the seashore or in the woods, the groups that hold reunions, and the great gatherings for patriotic celebrations or various kinds of pageantry—all gravitate naturally to the open spaces called parks. The link with nature must be established. In assisting in the development of areas where activities of this kind can be indulged in, the National Park Service considers that it is exercising a function of the utmost importance.

HYDROMETEOROLOGICAL SERVICES

By Merrill Bernard,[17] M. ASCE

The theme of this brief paper could well be, "How to eat your cake and have it, too." The "multiple-purpose family," made up of hydroelectric power, irrigation, municipal water supply, and navigation, was "getting along" most amicably until flood control came to live with it officially. Until then it had been the common purpose to maintain full reservoirs and to hold withdrawals from storage to business-like schedules. Furthermore, there had always been reasonable time for the adjustment of control works as the needs of changing power load, or a retarded irrigated crop, or deeper navigation waters were disclosed by these operations themselves. In other words, the conservation of stored water was to the common interest of all who were participating in a multiple-use project. However, flood control, demanding not a full, but an empty reservoir, has called for compromises which place on the operator the requirement that he "eat his cake" one minute and in the next have it, or wish he had.

Surface storage is created and sustained by the runoff from precipitation—in the west, largely from the seasonally controlled melting of snow deposited throughout the winter at the higher elevations; in the east, from storms confined to relatively short periods of practically continuous rainfall, the longest of which usually lasts 3 days or 4 days. It does not take much imagination to understand how easily optimum operating conditions could be maintained if the operator of a multiple-use reservoir had before him a record of the actual weather immediately ahead just as he has of the weather which has just passed—in other words, a perfect weather forecast. Such a forecast would have the range necessary to prepare for the beginning of runoff producing rains, the ending of the runoff period, or the beginning and ending of an extended rainless period. Unhappily, the operator can be provided with no such complete previsional operating schedule. However, the question can still be asked—have not the considerably less than perfect weather forecasts now available some operational value? The operator's answer to this question is that he has taken the fullest advantage of the national weather services but has found that the forecasts available to him are too short in range, not sufficiently detailed as to time and place, and subject to so low a verification as to be untrustworthy and even dangerously misleading. To support his case the operator points to the fact that the Corps of Engineers, the TVA, and the Bureau of Reclamation have made extensive use of the meteorologist, in both the design and the operational phases of multiple-purpose projects. Such claims are enough supported for the planning phase, as these agencies have supplemented their design techniques with hydrometeorological studies which have contributed much to structural security and program economy. However, when the comprehensive weather forecast (obviously the primary requisite of successful multiple-purpose operations) is needed, the tendency is to "let George (the

[17] Chf., Climatological and Hydrologic Services, U. S. Weather Bureau, Washington, D. C.

Weather Bureau) do it." It is not the writer's objective to alibi for "George," but rather to call the engineer-operator's attention to a responsibility that he himself has not altogether met.

The prevailing criticisms of weather forecasts, as they are issued to the public, are that they are too generalized, that they lack detail and continuity, and, therefore, that they cannot be used as operational forecasts. Such faults, it must be agreed, have no place in multiple-purpose reservoir operations which are sensitive to weather changes because they attempt on one hand to control the excesses of weather and at the same time offset the ill effects of its deficiencies on the other; but why has the engineer allowed the case to rest here? Modern aviation, whose entire operation rests on weather forecasts, did not allow the technical limitations of an applied science, or the service deficiencies of an old-line federal agency, or a less than perfect use of weather forecasting to prevent an accomplishment which engineers having the responsibility for river control can scrutinize with profit.

Weather forecasts in the United States are based on some 700 synoptic observations—the term "synoptic" indicating that these observations, being taken at the same time, give a picture of weather conditions "as of the moment." Having been plotted and analyzed, the observations serve as the basis for a wide variety of forecasts, the most immediate being the operational forecasts for aviation of all types—commercial, military, and private. First, there are the short-range trip and terminal forecasts which, on a hit or miss verification, score more than 90%. Next, are the airway regional forecasts used for flight planning as far ahead as 6 hours or 8 hours. These forecasts are translated into operational terms by the air line meteorologists and dispatchers; and, from them, estimates of arrival and departure times, pay load, flight levels, icing, and other operational hazards are determined. The operational forecasts for aviation are supplemented by state and local forecasts covering a range of from 12 hours to 48 hours. These forecasts, which are designed to serve the needs of the general public, are accurate in from 65% to 85% of the cases, depending on the range. A 5-day forecast is issued as a guidance forecast and for the assistance of those interests whose operations can be benefited even though verification for the fifth day shows little skill—that is, little improvement over the probabilities that can be derived from the statistical use of climatological data.

The forecasts discussed thus far have been based on current reports of meteorological conditions. Multiple-purpose operations in the west are served directly by the water supply forecasts of the Weather Bureau which are synoptic in the sense that they are based on observed conditions, even though the time interval is 30 days long. The forecasts begin on January 1, when about half of the data used in the computations is observed and half is statistical. Forecasts are then issued as of the first of each succeeding month, through May, progressively substituting observed data for the statistical at which time practically all data are observed. Water supply forecasts are issued for about 270 points in the Columbia, Missouri, Colorado, Sacramento, Great Basin, Platte, and Rio Grande basins.

The writer has discussed the "synoptic forecasts" applicable to weather immediately ahead. Despite their limitations, these forecasts must be used as the basis for any operation demanding quick adjustment of controls designed to maintain the highest reservoir levels commensurate with the storage of flood runoff when such occurs. Another kind of forecast is the "statistical forecast." That little use has been made of the statistical forecast as a basis for planning and as a base on which to superimpose the short-range synoptic forecast is attested by the fact that the climatological data necessary for the development of such techniques now lie dormant and practically unused in the repositories of the Weather Bureau. The explanation is simple. Throughout the 50-odd-year period of record more than one billion items of climatological data have accumulated. Such a mass of material, in its present unorganized state, defies processing and analysis by manual procedures. Long since have the average or so-called "normal" values published by the Weather Bureau demonstrated their inadequacy and inapplicability to the present-day statistical problem. Only now (1948) have funds been provided for the Weather Bureau to place the currently collected data on punched cards, an operation which is being carried out at seven weather records processing centers throughout the United States. Even then, it will be a long time before the huge backlog of data has been reduced to decks of punched cards available for summarization, analysis, and application to the solution of engineering problems.

The larger engineering organizations responsible for operating control works which must serve both for regulating floods and for utilizing water have recognized the weather forecast as an essential operational need but, in the writer's opinion, are limiting themselves too restrictedly to those forecasts that can be provided by the Weather Bureau. The business of taking observations and preparing the resulting data for analysis and the issuance of weather advices to the public are basic functions of the Weather Bureau. However, as demonstrated by aviation, the beneficiary of a specialized and detailed operational forecast must be prepared to accept the cost as he would any other item of operational expense. The course to be followed is not one of duplicating the services of the Weather Bureau but of supporting operational staffs with meteorological "interpreters" and in developing techniques which will express the forecasts in operational terms. Just as cooperative hydrometeorological studies of the Corps of Engineers, Bureau of Reclamation, and Weather Bureau have provided design criteria so could the same cooperative effort provide the tools needed by the weather forecaster to make successful forecasts for reservoir operation.

STATE AND FEDERAL GOVERNMENT PARTICIPATION

BY DON MCBRIDE[18]

This paper presents some rather important aspects of the relations between the federal government and the respective state governments as they pertain to the question of multiple-purpose water resource development—one of the broadest of the several fields of joint federal-state interest. In fact, it would be difficult to name another that has a more direct bearing on the economic welfare and the security of so many individuals. In recent years this relationship has been the topic of considerable controversy and discussion which probably will grow in tempo as federal water control and development projects become increasingly more important in changing and shaping the economy and the national security. This matter is of particular concern to the engineering profession.

The types of activities concerned with the physical control and utilization of water include irrigation, navigation, flood control, hydroelectric power, fish and wildlife protection, drainage, recreation, municipal water, sewage and industrial waste disposal, pollution control, and sediment control. These activities are highly important to the people of all the states, and are generally of vital economic significance throughout the seventeen western states. The federal government has moved into these fields with great vigor in recent years and has embarked on wide-scale programs of planning and construction, principally under the Corps of Engineers and the Bureau of Reclamation. Some of the state governments feel that the federal government has encroached too much on state jurisdictions, or "State rights," in carrying on these programs. They feel that the federal agencies executing the programs are attempting to dictate to the states the kind, the extent, and the programming of developments, regardless of state or local views.

Such a situation will surely affect all resource programs adversely. If there is any field of endeavor in which there should be complete understanding and agreement and effective cooperation between the state and federal governments, it is in the use, control, and development of water resources. Both state and federal governments, in the interest of the economic welfare and the security of the nation, have a vital stake in this undertaking.

The United States at present is in a period of postwar transition during which the economic and political structure is undergoing some drastic changes born of conditions that grew out of, or were accelerated by, World War II. To use a cliché that expresses the situation quite well, the nation is "at the crossroads." This is a good time to examine clearly the past, present, and future of that structure. Engineers should understand the "whys" so that they may do a better and quicker job of defining and attaining their goals in resource conservation and development. They must be realistic and must deal in-

[18] Secy.-Mgr., National Reclamation Assn., Washington, D. C.

telligently and opportunely with water resource problems. Throughout the United States, citizens cannot continue to suffer huge human and economic losses from floods; and the western states have reached a point at which present stability and future growth will be measured by the expansion of irrigation and hydroelectric power, regardless of what agency does the job. These facts need to be faced now, and workable solutions found. The federal-state relationship is particularly in need of clarification. In the early part of the twentieth century, there was little question about state responsibility for water resource development. The United States stayed quite closely to fields of undisputed federal jurisdiction, such as navigation and the reclamation of public lands.

The nation was growing fast and the economy was expanding without much thought of centralized planning for irrigation, power development, flood control, and other water resources, or for the other elements of national economy. Things just seemed to grow of their own accord, and the few who raised warning voices that the nation was heading into trouble because of unplanned development and use of resources were either ignored, defeated, or shouted down as malcontents and radicals not worthy of an audience of serious men.

Projects sprang up wherever a few people got together and formed irrigation districts, or wherever a few communities brought out some concrete proposal for flood protection. Few people gave much thought to the day, now here, when "the cream would be skimmed off" potential irrigation developments and when careful engineering and economic planning of water uses would be necessary. Soil and forest depletion, the devastation of the grazing lands, and other conservation problems were matters for interesting discussions and heated arguments, but little was done about them. Urban and rural sections suffered recurring floods. People scooped the mud out of their homes and shops, cursed the river, said "somebody ought to do something about it," but never quite got around to the point of getting the job started. Farmers suffered recurring droughts and economic ruin while the precious water they needed flowed down the river systems and wasted into the seas, incidentally carrying a good measure of soil with it.

During all this time, the states had opportunity and incentive to move into the field of intelligent planning and development of water resources but very little was done. It is true that some of the states did make attempts in that direction, but their efforts did not produce the results demanded by the situation.

In 1917, Congress passed the Newlands Act, which provided for coordinated state-federal planning of water resource development, with full provision for preserving the rights and jurisdictions of state and local governments. This law was repealed in 1919 as a result of the activities of myopic individuals who failed to comprehend, or chose to ignore, the conditions looming on the horizon that eventually led to federal action.

The writer does not seek to condemn or reprimand the states, and he dislikes very much to point to this situation with a critical finger; but it is high time that a little soul searching was done in regard to this topic. Engineers must look at it as technicians, and without the emotional responses that sometimes handicap a scientific approach to political and social questions.

In retrospect, one can see that the nation has allowed a critical water resource situation to grow, which cried louder and louder for sound public leadership and planning. What was needed in the semiarid and arid west was patently a sound inventory of potential water resources, a realistic appraisal of water needs, current and long time, looking toward ultimate full development, and a programming of work that would enable development to keep step with needs. Unquestionably federal aid and participation in such an undertaking would have been necessary, but the basic "spadework" and the responsibility for taking the initiative in planning and programming, and for a high degree of control over the entire undertaking, rested with the states. It is not necessary to discuss why the states failed to meet this challenge with the speed and vigor demanded.

When the crisis precipitated by the economic depression in the 1930's brought about a public examination of the entire economic and political life of the nation, the federal government moved into the province of planning resource development and conservation where the failure of state action had created a vacuum. The National Resources Planning Board and other federal agencies attacked the problem on an engineering basis, by an inventory of what there was, a computation of what was needed, an over-all plan of action, and a program of necessary steps.

How the federal government launched an expanded program for reclamation, flood control, improvement of rivers and harbors, soil conservation, and other resource measures is a well-known story. The United States Supreme Court smoothed out the legal way with decisions, in the New River and Red River cases, that recognized the theory of navigability and federal jurisdiction over streams from source to mouth. Then came legislation in 1933 establishing the TVA. This new system of resource development plagues many today in view of its impact on what are considered the time-honored fundamentals of government.

The threat of change in procedures has made this nation great; it hangs over all heads like the "Sword of Damocles," and greatly disturbs many. The threat can be removed if methods are devised for implementing river resource development within traditional democratic principles and practices of government, using traditional government administrative agencies. Excellent progress has been made in demonstrating that the job can be done without resorting to the valley authority system, and the risk implied; but there is much room for improvement.

Today, there is considerable confusion, hesitation, and much downright squabbling over the further development of water resources. The planner is confronted with conflicting laws bearing on the matter, with differences of opinion as to the hydroelectric power aspect of the irrigation and the flood control programs, with the need of a comprehensive national water development policy that would keep planning agencies in step and help them reach their goals, and with the failure of too many states to meet their responsibilities. Out of this confusion a stronger and stronger sentiment is growing to rectify this situation. Without positive action there are better and better prospects that the public, in some time of crisis, may call for and obtain a full-fledged valley

authority system of administering developments. There is manifestation of this confusion and disorganization in the Eightieth Congress in the several bills seeking to adjust the development of hydroelectric power as a working and paying side partner of irrigation development and as an aid to economic justification of flood control projects. If the matter is not straightened out fairly quickly it is a good bet that valley authorities will become accepted as normal.

Two of the most important subjects that need clarification are the federal-state relationship and state responsibility. Engineers should approach this problem with the realization that the federal government is in the water resource development business to stay. Their task, then, is to build the best possible cooperation and coordination between the federal and the state and local governments. The prospects for success in this connection, and for a beneficial effect on resource development, are bright.

The writer prefers, as a cornerstone, Section 8 of the Reclamation Act of 1902, which states, in part: "That nothing in this Act * * * [is] intended to interfere with the laws of any State relating to the control, appropriation, use or distribution of water. * * * "

Even as it moved broadly into the field of resource development and conservation coincident with the depression of the 1930's, the federal government recognized State rights and provided for state participation. The National Resources Board urged the states to establish permanent state planning boards and to develop, as promptly as possible, adequate state planning programs. Continued cooperation with, and encouragement of, state and local planning work and assistance in handling interstate and regional problems were urged on the federal government by the board.

A few of the states responded by establishing engineering planning organizations and forming programs for making effective use of federal aid, but most of them did not. As a result, the river resource programs developed were largely the result of thinking and planning by federal agencies, with a minimum of influence from state agencies. It is well to remember that the first flood control act (1936) required states to secure right of way, and to maintain and to operate flood control reservoirs. The act was amended in 1938, without opposition from the states, to make all these functions the responsibility of the federal government. The states apparently were not willing to accept responsibility and to bear the financial obligation that the 1936 act imposed upon them.

The 1944 flood control act is a federal law which puts it squarely up to the state governments to discharge their responsibility for participating in the planning of river basin developments. That act contains an outright declaration of Congressional policy—

> "* * * to recognize the interests and rights of the States in determining the development of the watershed within their borders and likewise their interests and rights in water utilization and control, * * *."

The law requires that the Corps of Engineers and the Bureau of Reclamation give the interested states full access to data gathered during the course of the

resource development investigations. It requires that the states be given an opportunity for consultation regarding federal plans and proposals and, to the extent deemed practicable, an opportunity to cooperate in the investigations. It requires a similar degree of cooperation between the two federal agencies with respect to the investigations that each conducts.

The law requires that the originating federal agency submit a copy of its proposed report to each of the affected states before submitting it to Congress, as well as to the other federal agency. It provides that the states and the other federal agency shall send comments on the report to the originating agency, and that the latter shall forward the report and all comments to Congress, along with the comments of the originating agency.

The federal agencies interested in water, and related resource development review and coordinate their programs through a federal inter agency river basin committee. To provide for even closer cooperation in the localities where problems arise, subordinate local inter agency committees have been established for the Missouri and Columbia river basins, with provision for representation by the state governments.

A recent survey conducted by the writer indicates that very few of the western states are taking any appreciable advantage of the opportunity afforded them by this law for vigorous participation in the planning and the programming of resource developments. Many of the states, for lack of funds and personnel, are not in a position to make thorough reviews of federal reports. In other cases, the states are so thorough in their investigations and reports that the result is almost the equivalent of sending two different reports to Congress on the same subject.

Some of the states have procedures for holding hearings for the purpose of ascertaining the views of the people directly affected, as an important guide to state review of federal plans; but most of them do not provide their people with this kind of service. To discharge its obligation fully, each state should take an inventory of its water resources, establish definite goals for their development, establish procedures for ascertaining public views on federal projects, set up and use effective engineering machinery to gear federal programs to state needs, and do all this economically. Cooperation of this type at the inception of planning would be highly beneficial and is earnestly desired and provided for under federal law and procedures.

J. E. Hobson, director of the Armour Research Foundation, Chicago, Ill., in an address has stated:

> "Government is a servant of the people and therefore should be told what its role is to be. Government should not tell the people. It is for the people to decide how Government can best serve them."

This is a fine expression of sound government policy; but, when the people stand mute, the government can be expected to move ahead without the benefit of their expressions. Progress cannot be held back in the development of river basin resources. In other words, as long as the states fail to undertake a program of vigorous and effective cooperation and participation in resource development, the federal government will maintain the initiative and anticipate

a minimum of state influence. Without clear-cut definitions of goals and expressions of public views and needs, and without strong state leadership along sound engineering lines, there will be areas of friction in federal-state relations, rather than smooth coordination.

The location, design, operation, and purposes of reservoirs present problems that should not be too difficult to solve to the satisfaction of all requirements—local, state, and federal—if the states give appropriate engineering attention to federal proposals and are willing to approach the matter in the old-fashioned spirit of the greatest good for the greatest number of people.

With the passing of time, multiple-purpose projects will become more and more complex, and planning agencies will be faced with more complications from the standpoints of design and operation than heretofore. Therefore, such projects must be scrutinized very carefully to produce sound economic and beneficial use.

From the standpoint of the state engineer, certain principles should be basic in the design of multiple-purpose projects. If the costs of the project are to be repaid from earnings, it is particularly necessary to check proposed plans carefully in the interest of preserving the most stringent economy. There may be a tendency to overdesign structures if the project is entirely or heavily nonreimbursable, and sound public policy requires that all care be used to ascertain economies that might be effected without impairment or risk. A careful study may show that to stand the property losses from a flood stage that might be reached once or twice in a century would be much cheaper than to design a structure for such an unusual occurrence. Such matters as spillway designs, destruction of agricultural values by the inundation of lands in the reservoir area as compared with the creation of agricultural values below the reservoir, and the effect of such changes in land values on local government subdivisions are some of the problems that affect the state engineer's viewpoint.

In response to inquiries from the seventeen western state engineers as to the basic principles of design and operation of multiple-purpose projects, the following seem to predominate:

1. Multiple-purpose operation of reservoirs should not be attempted unless conditions are favorable;
2. Operation should be planned to result in the optimum benefit being derived even if operation for one use may be detrimental to another;
3. Reservoirs should not be operated to produce a benefit if that benefit can be obtained at a lesser cost by some other procedure;
4. Separate allocation of storage capacity for each use is essential; and
5. Preference of use should be the controlling feature of design and operation of any reservoir.

The need for a comprehensive national policy is crystal clear. The federal government, at the outset, was concerned solely with navigation. The close connection between that function and flood control led the federal government into the latter field. Reservoirs built for reclamation were suitable for irrigation, hydroelectric power, and other uses. As new situations were encountered,

including drainage, pollution abatement, sediment and derbis control, soil conservation and erosion control, water supply, recreation, and fish and wildlife conservation, the government was led inevitably into participation in the entire field of water resource development.

Governmental entry into these fields was usually marked by an act of Congress, establishing the government's policy to meet the particular need in question. In this manner, the national water policies and activities have been developed piecemeal and have lacked careful coordination and codification into an integrated instrument. As a result national policies are frequently inconsistent and conflicting, jurisdications overlap, and gaps occur in the over-all policy structure. Leaders of water resource development have long felt the need of a consistent national water policy which will result in full economic development in the interest of stable growth of the region, state, and nation.

The Subcommittee on Appropriations for the U. S. Department of the Interior, in reporting the appropriations bill, cited the need for a national public power policy, as follows:

> "At present the Appropriations Committee has to consider requests from various Government departments for funds for the production and distribution of power and each department and agency has a different plan or system from the others. The issues involve the type of transmission systems, priorities of customers, interest charges, and rate structures; therefore, in the opinion of the committee a sound uniform and coordinated power policy should be written into law to guide the Congress and its committees in making appropriations and authorizations for projects which contain hydro-electric power incidental to water resource development. If the power is to aid the projects, it must be marketed to assure economic stability of the project.
>
> "The desirability of an over-all policy is clear. This is a legislative matter, however, beyond the jurisdiction of this committee, but it agrees that there should be such legislation, particularly with respect to both the application of the interest component and the public power policy, and in the opinion of the committee this should be the subject of immediate legislative action."

The controversy over the development of hydroelectric power has injected much confusion into the water resource development picture. Everyone must realize that hydroelectric power is an essential and inseparable part of any water resource development. If the nation is to go forward with large-scale irrigation and related resource developments, it must depend upon the widespread sale of hydroelectric energy made at federal dams and, where necessary, carried by federal transmission lines to points of wholesale delivery. This procedure is necessary to defray project costs. Power is needed to build the industrial economy that must go hand-in-hand with western agricultural growth. It lightens the burdens of rural life and will brighten many a western home.

The 1944 flood control act was "a step in the right direction," containing provisions dealing with hydroelectric power, irrigation, priority of water use, water supply, and recreation. Much more remains to be done, however, and should be done expeditiously to unite all interested agencies in a common, coordinated effort.

Briefly, to summarize all the foregoing:

a. Instead of holding back or obstructing federal programs, the states should strive together and separately to improve the coordination and the effectiveness of federal work.

b. The states should exercise fully their responsibility for participation in the inception of projects, and for adequate engineering reviews and public expressions in the interests of promoting economy and adaptability to state and local needs.

c. The states should cooperate in the establishment of a federal water policy that would define the rules of the game so that all agencies can work together more effectively.

d. Continuance of the present high degree of indifference, and failure to come forward and exercise the responsibility attending State rights, is to risk perpetuating and increasing the present state of confusion. This result certainly would promote the germination of the already planted seeds from which valley authorities might some day grow.

In his rather frank criticisms of the states, it is the writer's hope that he has not minimized the fact, nor left the false impression, that the federal agencies interested in the development of national resources have a lesser responsibility than do the states.

SUMMARY AND REVIEW OF PRINCIPLES

By Raymond A. Hill,[19] M. ASCE

This Symposium contains thirteen papers on the subject of multiple-purpose reservoirs. Some of them review the development of the principles governing designs; some illustrate the application of such principles in actual operating practice; and others, by authors who influence the design and the operation of such reservoirs, explain functions and viewpoints.

In this final paper it seems appropriate to call attention to a certain divergence in views expressed in the papers and to emphasize some of the basic factors that should be considered in the design and the operation of multiple-purpose reservoirs. It should be understood that any opinions expressed are those of the writer and are not necessarily endorsed by the Joint Committee on Design and Operation of Multiple-Purpose Reservoirs as such.

Definition of Multiple-Purpose Reservoirs

In the "Introduction" made on behalf of the committee, it was stated that:

> "* * * the term 'multiple-purpose reservoirs' should include all reservoirs actually designed and operated to serve more than one function and that it should exclude those whose design and operation are controlled by a single function even though other benefits accrue as by-products."

It would appear that those authors representing the various federal agencies consider that this definition is too restrictive and that every reservoir serves, or at least should serve, more than one purpose. As a corollary to this proposition, it would follow that indirect benefits will result from the operation of any reservoir and that these benefits may be used to offset the costs of construction.

Conflicting Requirements

When the concept of designing a reservoir for more than a single purpose first became popular, the problem was only one of reconciliation between the regulation of stream flows over a short period for flood control and the regulation over extended periods for irrigation, power production, or navigation. In recent years, however, fish and wildlife protection and propagation, recreational uses of reservoirs, and other functions have come to influence, materially, the design and the operation of multiple-purpose reservoirs.

The requirements of reservoir operation to satisfy these several uses are fundamentally conflicting; thus:

(*a*) Regulation for flood control is best accomplished when reservoirs are kept empty in anticipation of floods and are evacuated as rapidly thereafter as circumstances permit.

(*b*) Conservation for irrigation or domestic use requires that floodwaters be held in storage, sometimes over a period of years in the semiarid west, that

[19] Cons. Engr., Leeds, Hill and Jewett, Los Angeles, Calif.

the release of water be in conformity with seasonal demands, and that at times all water be withdrawn for use.

(*c*) Regulation of stream flows for the production of hydroelectric power requires that reservoirs be kept as nearly full as practicable, that they never be emptied, and that the release of water be made in accordance with demands for power and energy.

(*d*) Maintenance of a stable reservoir level is most favorable to fish and wildlife protection and propagation and in no event may such a reservoir be emptied.

(*e*) Recreational purposes are best served when a reservoir is kept full, simulating conditions as natural lakes.

There is less conflict between irrigation and power than between either of these and flood control, in that conservation of floods and regulation of releases over extended periods of time are essential to both. However, except in limited areas where the power load happens to conform to irrigation demands, reregulation of water released for power production is necessary, as is cited by Mr. Nelson in his description of Elephant Butte and Caballo reservoirs on the Rio Grande. Without Caballo Reservoir below it, Elephant Butte Reservoir could be operated only to satisfy irrigation needs and power would have been but a by-product; but, with power releases reregulated by storage in Caballo Reservoir, firm power can be produced. In this case it took the coordination of operation of two reservoirs to constitute a multiple-purpose project. In general, it would appear that, where the requirements of irrigation and power must both be met, a series of reservoirs is needed and that no single reservoir can serve these multiple purposes without waste of water. Such waste cannot be permitted where agriculture is dependent on irrigation.

Coordination of the requirements for fish and wildlife propagation and for recreational uses of reservoirs with the requirements for either flood control or irrigation is almost impracticable. The fluctuations in stage characteristics of reservoirs operated for such purposes make them unsuitable for recreational use and fish can be protected only if a minimum pool is maintained. Flood control reservoirs are particularly subject to rapid changes in level; irrigation reservoirs must be emptied of all water whenever it is needed for delivery to farms.

Obviously, the conflicting requirements of flood control and irrigation, or of flood control and power production, could be avoided by pyramiding capacities. For example, if 1,000,000 acre-ft of storage was deemed necessary for conservation and 500,000 acre-ft was needed for flood control, a reservoir of 1,500,000 acre-ft could be built and the component parts could be operated in effect as separate reservoirs.

Such superimposition of capacities would not be inconsistent with the philosophies of the Corps of Engineers; on the other hand, it would be contrary to the principles advanced by other federal agencies who hold that dual use of reservoir capacity is practicable and economically desirable. Various illustrations were given of the feasibility of using flood control storage for seasonal regulation of stream flows to conform to the requirements of irrigation,

hydroelectric power, or navigation. In this connection it was shown by Mr. Bernard that a wealth of data has been accumulated from which statistical forecasts could be made.

Economic Factors

In the design of any reservoir, therefore, which is intended to serve more than one purpose, such conflicting requirements must be compromised, unless there is to be a pyramiding of capacities and costs. No such compromise of conflicting requirements can be made intelligently without consideration of the relative values involved. Hence, the design of a multiple-purpose reservoir is fundamentally an economic problem.

Although little was mentioned about costs and benefits by the authors representing the various federal agencies which construct such reservoirs, it is a matter of common knowledge that there is little agreement among them as to the basis of determining benefits. Some people in government service believe that any expenditure of taxes is justified if it does not exceed the total of all benefits deemed to flow from that expenditure. Others in private industry maintain that the economic system depends on rigid application of the rule that every investment should earn a rate of return commensurate with the risk involved. Reconciliation of these opposing philosophies is just as important as compromise of the conflicting requirements of operation of multiple-purpose reservoirs.

The rule of private industry must remain applicable to the investment of private capital because such investments are dependent on direct benefits only. On the other hand, governments can afford to make greater capital expenditures because of the indirect benefits accruing to the taxpaying public; but there is reason to question expenditures beyond the point where the incremental cost exceeds the incremental benefit.

Benefits arising from the construction of any multiple-purpose project approach an upper limit as the capacity provided in the reservoir is increased. Costs of construction, on the other hand, normally include some substantially fixed items and become tremendous whenever the size of the reservoir exceeds the limitations of the site. If typical curves are plotted showing the relations between benefits and reservoir capacity and between costs and reservoir capacity, it will be found that these curves intersect at two points; below some small capacity the costs will exceed the benefits and beyond some much greater capacity the benefits again become less than the costs. Between these limiting amounts there are two values of particular significance:

(1) The reservoir capacity at which the ratio of benefits to cost is a maximum; and

(2) The capacity at which the difference between benefits and costs is a maximum.

Referring to Fig. 15, it will be found that, for any reservoir capacity between 0.3 unit and 8.3 units, the benefits (curve 1) exceed the costs (curve 2). The maximum dollar difference between benefits and costs occurs for a reservoir 3.3 units in size, which is 40% of the upper limit where the costs become as great as the benefits; the maximum ratio of benefits to costs (curve 3, Fig. 15)

occurs for a reservoir of 1.9 units of capacity, which is only 23% of the same upper limit.

The lower limit at which costs exceed benefits is of little practical significance but reservoir capacities corresponding to the other three values determined in this illustration must be given consideration in the design of any multiple-purpose reservoir. There is usually ample justification for providing storage capacity up to the quantity at which the ratio of benefits to costs is a maximum, and reasonable justification for increasing the capacity beyond this size up to the point where the difference between benefits and costs is a maximum. There would seem to be little justification, however, for providing any reservoir capacity in excess of that required to produce the maximum difference between benefits and costs (curve 4, Fig. 15), because beyond that point it takes more than a dollar of taxes to derive another dollar of benefits.

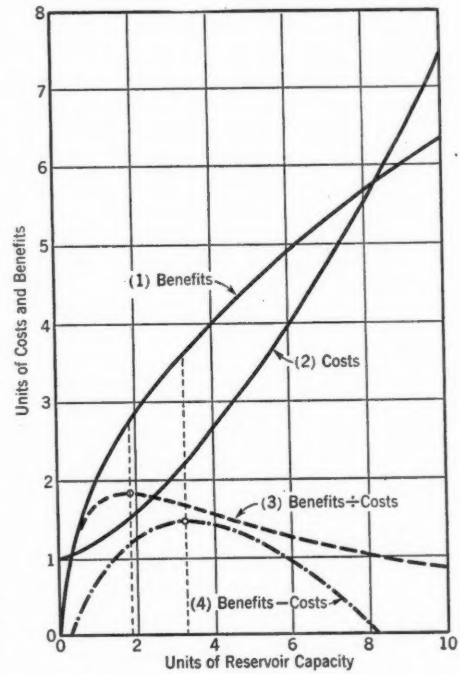

Fig. 15.—Relation Between Benefits and Costs of Multiple-Purpose Reservoirs

In any such comparison of costs and benefits of multiple-purpose reservoirs, the benefits deemed to arise out of the reservoir must be as tangible as the costs themselves. When a dam is built, capital is then invested and it is immaterial whether such capital be obtained directly from the public by the sale of securities or whether it be obtained indirectly from the public by the levy of taxes; in either case real dollars must be used. It follows that, if such benefits are to outweigh the costs, these benefits must have substance. Furthermore, whenever those who benefit directly from a multiple-purpose reservoir do not bear its cost and the project must be subsidized by the public at large, consideration should also be given to competitive benefits—that is, to benefits that would be derived from the expenditure of equal sums for other purposes or at other locations.

Summary

It would seem to be evident, if all secondary uses and by-products of a multiple-purpose reservoir are to be considered in its design, that:

1. The conflicting requirements of all possible uses of the reservoir must be compromised;

2. Compromise of such conflicting requirements will depend on evaluation of each direct and indirect benefit that will actually be realized in the operation of the reservoir;

3. The sum of all such benefits must be substantially more than the costs of construction and operation; and

4. Due consideration must be given to the competitive benefits which would accrue from like expenditures at other locations or for other purposes.

In brief, the design of any multiple-purpose reservoir is basically an economic problem. The solution of such a problem in the best interests of the nation requires that the present confusion of philosophies and practices be resolved, and that rational, uniform, and sound economic principles be established for the design and the operation of multiple-purpose reservoirs.

AMERICAN SOCIETY OF CIVIL ENGINEERS
Founded November 5, 1852

DISCUSSIONS

MATRIX ANALYSIS OF PIN-CONNECTED STRUCTURES

Discussion

BY PEI-PING CHEN

PEI-PING CHEN.[8]—Professor Oldenburger's comments concerning the restriction of the matrix approach to linear, first-order effects are well taken. Although it is not inconceivable that matrix technique could be adapted to the treatment of nonlinear problems, in the present application the matrix equations serve only as a convenient (and powerful) shorthand for sets of simultaneous linear equations. The statement that the matrix γ is a direct product of a vector by itself is not strictly correct. The matrix γ is actually proportional to a Gibbs product of a unit vector by itself; thus:

$$\gamma = \frac{E\,A}{L}\begin{bmatrix} X/L \\ Y/L \\ Z/L \end{bmatrix}\begin{bmatrix}\frac{X}{L}, \frac{Y}{L}, \frac{Z}{L}\end{bmatrix} \quad\ldots\ldots\ldots\ldots\ldots\ldots(27)$$

Mr. Floris' observation that the method presented is "distinctly new" is greatly appreciated, since it may be true, as Mr. Floris suggests, that the basic approach may not have been understood by the reader who is not on intimate terms with matrices. It may be well to discuss briefly the underlying philosophy of the present approach, to compare it with standard methods, and to make evident the superiority of the present method for certain types of problems. In standard methods the problem of analyzing trusses is roughly as follows:

1. The hyperstatic, or redundant, bars are "removed" and replaced by unknown forces;
2. The forces in the remaining bars are computed by statics (method of joints, method of sections, etc.) in terms of the unknown forces and the applied loads;

NOTE.—This paper by Pei-ping Chen was published in December, 1947, *Proceedings*. Discussion on this paper has appeared in *Proceedings*, as follows: June, 1948, by Rufus Oldenburger; and October, 1948, by A. Floris.

[8] Fellow in Applied Math., Brown Univ., Providence, R. I.

3. Simultaneous equations are set up and solved for the unknown forces in the redundant bars; and
4. The forces in the remaining bars are then found from the results of steps 2 and 3.

The chief difficulty generally occurs in step 3. Thus a structure with six redundant bars requires the solution of six simultaneous equations. In addition, if displacements of the truss are desired, further computations are required using one or another of the standard methods of finding truss deflections.

In the present method the procedure is as follows:

a. The forces in the bars are computed in terms of the displacement components of each joint;

b. From equilibrium considerations, simultaneous equations are set up and solved for the displacement components; and

c. From the results of steps *a* and *b*, the forces in each bar are computed directly.

Again, the chief labor comes in solving the simultaneous equations of step *b*. However, in this case, both stresses and displacements will have been computed on completion of steps *a*, *b*, and *c*.

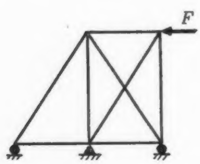

FIG. 5

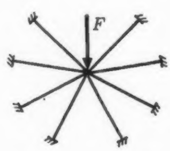

FIG. 6

Although a truss with, say, two redundant members and six unknown joint displacement components (see Fig. 5) is best handled by standard methods, it is considerably more advantageous to use the writer's approach for analyzing a truss with six redundant members and only two unknown displacement components (see Fig. 6).

Furthermore, if the inverse matrix $(\alpha')^{-1}$ is computed at the outset, the truss may be solved for a large variety of loadings with little additional labor, whereas standard methods generally require the repetition of almost all computations for each set of loads.

Corrections for *Transactions:* In December, 1947, *Proceedings*, on page 1480, in line 28 (last line of the matrix for α'), change "1.36" to "1.64"; and, on page 1481, line 9 (just below Fig. 4), change "Λ" to "δ" in three places.

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DISCUSSIONS

ADJUSTMENT OF THE "SHORAN" TRIANGULATION

Discussion

BY ROBERT C. SHELDON, AND H. W. HEMPLE

ROBERT C. SHELDON,[2] Assoc. M. ASCE.—A method of adjustment that is to be used with "shoran" measurements is presented in this paper. These measurements differ from conventional triangulation measurements by giving field data in lengths without direction in place of the usual directions without lengths. The lengths of the courses in any given figure do not provide as complete control of the figure, for adjustment purposes, as the several angles. The author proposes a system of pentagons with distances between all stations measured. This will tend to provide strength that is lost by not observing the angles of a more simple figure.

The proposed method consists of obtaining approximate positions for the several new stations in any manner. The author has suggested: (1) Computations using the field data, (2) use of the field data graphically on a stereographic projection, and (3) the possible use of astronomic positions. These approximate positions are then to be corrected by the method of least squares with the simultaneous solution of equations formed from computed and field data of the several lines.

In deriving the formulas by which these comparisons are made the author first shows that any change (in either length or direction) of any line in space is related to the changes in the space coordinates of its extremities by the relations shown in Eq. 3*e*. The direct relation between the space coordinates of the extremities of this line in space and the latitude and longitude of the same points on an ellipsoid of revolution is then shown by Eqs. 4. Eqs. 5 indicate that any changes in latitude and longitude on this ellipsoid are related to the changes in their corresponding space coordinates by the relations given. The substitution of Eqs. 5 in Eq. 3*e*, to form Eq. 6, thus gives the effect of any change in the line in space on the latitude and longitude of its extremities on an ellipsoid of revolution. The change in the line of space is the amount of correction necessary to bring the measured length of the chord in agreement with the computed length between the approximate stations.

NOTE.—This paper by Chung-jui Chu was published in September, 1948, *Proceedings*.

[2] Civ. Engr., Marietta, Ga.

For further simplification, Eq. 6 can be written

$$\Delta c_{12} = \text{KI}\,\Delta\phi_1 + \text{KII}\,\Delta\phi_2 + \text{KIII}\,\Delta\lambda_1 + \text{KIV}\,\Delta\lambda_2 \quad \text{(22)}$$

in which Δc_{12}, KI, KII, KIII, and KIV are numerical values for any given line. Eq. 22 with the numerical values will be used in the least squares adjustment of the net. It is in the determination of the numerical values for the constant Δc_{12} and the coefficients KI, KII, KIII, and KIV that the proposed method becomes laborious.

The constant Δc_{12} would be determined first, as the length of the chord c_{12} used to find Δc_{12} is also used in determining the coefficients KI, KII, KIII, and KIV:

$$\begin{aligned} c_e &= \sqrt{(x' - x^2)^2 + (y' - y^2)^2 + (z' - z^2)^2} \\ &= \sqrt{(N_1 \cos\phi_1 \cos\lambda_1 - N_2 \cos\phi_2 \cos\lambda_2)^2 + (N_1 \cos\phi_1 \sin\lambda_1 - N_2 \cos\phi_2 \sin\lambda_2)^2 + (N_1 (1 - e^2) \sin\phi_1 - N_2 (1 - e^2) \sin\phi_2)^2} \quad \text{(23)} \end{aligned}$$

Tables could be prepared for the N-values in Eq. 23 and for the term $N\,(1 - e^2) \times \sin\phi$; but tables for other values would be prohibited by the fact that they contain both latitude and longitude. It is apparent that the solution for the numerical value for c_e would require eight separate logarithmic computations and four arithmetic summations. Having found a value for c_e it can be used for c_{12} in finding the coefficients for Eq. 22.

$$\begin{aligned} \text{KI}_{12} = N_1 \Bigg\{ &\left[\left(\frac{N_1 \cos\phi_1 \cos\lambda_1 - N_2 \cos\phi_2 \cos\lambda_2}{c_{12}}\right) \sin\phi_1 \cos\lambda_1\right] \\ &- \left[\left(\frac{N_1 \cos\phi_1 \sin\lambda_1 - N_2 \cos\phi_2 \sin\lambda_2}{c_{12}}\right) \sin\phi_1 \cos\lambda_1\right] \\ &+ \left[\left(\frac{N_1 (1 - e^2) \sin\phi_1 - N_2 (1 - e^2) \sin\phi_2}{c_{12}}\right) (1 - e^2) \cos\phi_1\right] \Bigg\} \quad \text{(24)} \end{aligned}$$

Since the numerical values for several terms in this equation have already been determined, the solution requires only four logarithmic summations and one arithmetic summation. Coefficients KII_{12}, KIII_{12}, and KIV_{12}, would require similar computations.

To explain further how fixed locations of points are obtained from the method, the simple case of one point E located from two fixed points A and B in Fig. 4 can be shown. Although Fig. 4 is a plane drawing it can be assumed to represent a part of the surface of an ellipsoid of revolution. The three points are held to this surface by the relations expressed in Eq. 6. By substituting in Eq. 22,

$$\Delta c_{BE} = \text{KII}_{BE}\,\Delta\phi_E + \text{KIV}_{BE}\,\Delta\lambda_E \quad \text{(25a)}$$

and

$$\Delta c_{AE} = \text{KII}_{AE}\,\Delta\phi_E + \text{KIV}_{AE}\,\Delta\lambda_E \quad \text{(25b)}$$

As A and B are fixed points, the values of $\Delta\phi_A$, $\Delta\lambda_A$, $\Delta\phi_B$, and $\Delta\lambda_B$ are all zero

and the effect of the coefficients KI and KIII is lost. Chord corrections Δc_{BE} and Δc_{AE} are constants that can be determined and numerical values can be computed for KII_{BE}, KIV_{BE}, KII_{AE}, and KIV_{AE}, thus leaving two equations from which the two unknowns can be obtained. In this simple case the two measured chord lengths govern the position of point E without resort to any adjustment. Fig. 4 shows only a part of the pentagon in Fig. 1(*a*), on which

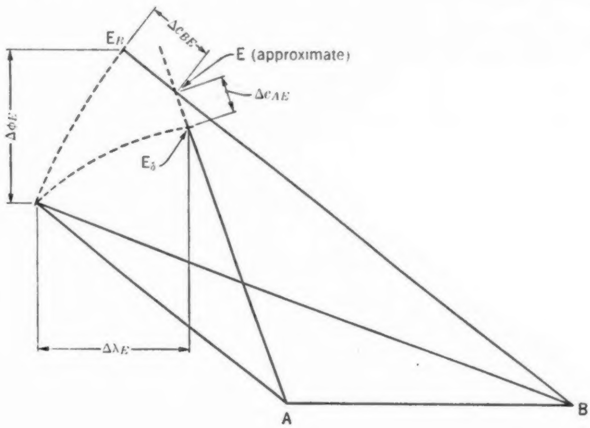

FIG. 4

it is proposed to use the method. It is apparent then, that the effects of all lines coming into point E from the several points of the pentagon, when adjusted by a least squares solution, will give the strongest probable position of point E obtainable from the measured lines.

The corrections finally found by the solution of the several equations will be in linear values (as can be determined by inspection of Eq. 6), corresponding to the unit of measurement used. The computation of the small angular values necessary for any precise determination of the locations of the points from these linear values will be difficult, using existing tables.

Although the method is called, "adjustment of 'shoran' triangulation," and although it does require adjustment in its processes, it can be said that it is primarily a method for computation of geodetic positions. Adjustment and triangulation enter only as minor factors. For this reason comparison must be made with the conventional method of computation of geodetic positions rather than with methods of adjustment or triangulation.

The method of computation in use in the United States (presented with tables elsewhere[3]) is limited to lines of 100 miles or less. By the introduction of the fourth term of the expansion of the Taylor theorem, as developed by H. M. Doolittle,[4] this limit is increased to several hundred miles. With somewhat smaller figures than those proposed by the author, precise adjusted positions can be obtained by the use of this conventional method (and tables) by

[3] "Formulae and Tables for the Computation of Geodetic Positions," *Special Publication No. 8*, U. S. Coast and Geodetic Survey, U. S. Govt. Printing Office, Washington, D. C., 6th Ed., 1919.

[4] *Ibid.*, p. 96, footnote (*e*).

computing the several triangles in the figure by their measured sides, and following the usual methods of adjustments. For the accuracies obtained by "shoran" the conventional method of computation would be satisfactory on the sides of 500 miles in length.[5] In any comparison between old and new methods the advantages is with the old, in that the tables and processes have been standardized, and that the work is routine. With the new method the preparation of tables, the arranging of forms for computation, and the actual calculations, are large projects.

"Shoran" is limited to long lines by the fact that the results have an error of accuracy fixed between definite limits, not dependent on the length of the line, rather than errors that are proportional to the length, as in the usual triangulation methods.[5] As "shoran" is used on lines long enough to have proportional errors smaller than the conventional methods, it becomes a very useful tool for geodetic surveys requiring long lines. It would be especially useful in carrying existing datums across large bodies of water to place isolated islands and continents on a common coordinate system. The solution of any problem of this type would be a special project for which ways and means would be devised to fit the particular case. It is the writer's opinion that the direct method of computation,[6] would be the proper approach in these cases.

The determination of the coordinated positions of geodetic monuments is but a step in the ultimate aim of fully coordinated maps and surveys. In 1948 it is beginning to be realized that one of the principal reasons for the reluctance of engineers and surveyors, in the United States, to use geodetic survey control in their surveys is the wide spacing of the control points. The U. S. Coast and Geodetic Survey is placing additional points, in certain locations, to bring the spacing of the national net from 25 miles to 12.5 miles. The State of Pennsylvania has adopted a maximum spacing of 5 miles in the state control system. Other organizations are supplementing the national net for practical use. The writer therefore believes that for surveys on land a system of points as suggested by the author (these points being without direction control unless such control is obtained by astronomic observation) would be of limited usefulness.

For the purpose for which it is recommended the author has presented a unique solution. It can be stated that the author has made a great step toward answering the challenge to geodesy implied in the statement made by Flecher G. Watson in 1946.[5]

H. W. Hemple,[7] M. ASCE.—One of the significant scientific advances resulting from World War II was the development of electronic distance measuring methods for use in surveying and mapping. These methods were originally used for positioning airplanes engaged on bombing missions to assist in locating targets, and for precise navigational purposes. Of the various electronic distance locating methods developed, the "shoran" method gives

[5] "Radar Shows Promise in Mapping," *Civil Engineering*, July, 1946, p. 294.

[6] "Formulae and Tables for the Computation of Geodetic Positions," *Special Publication No. 8*, U. S. Coast and Geodetic Survey, U. S. Govt. Printing Office, Washington, D. C., 6th Ed., 1919, p. 93.

[7] Capt., Chf., Div. of Geodesy, U. S. Coast and Geodetic Survey, Washington, D. C.

the best promise of attaining the accuracy necessary for geodetic survey purposes.

When it is used for distance determinations in geodetic surveying, the shoran equipment is mounted in an airplane. This airplane flies approximately normal to a line connecting two ground stations between which the distance is desired. At each of these stations, radio receiving and transmitting instruments are established. Radio impulses are transmitted from the airplane to the ground stations, amplified, and retransmitted back to the receiving device on the plane. There are two dials on the receiving equipment in the plane—each of which indicates the distance in miles from the plane to a corresponding ground station. The altitude of the plane is also determined, usually with an electronic altimeter. When the plane is on the line between the two ground stations, the sum of the distances from the plane to the ground stations will be a minimum. These distances are then reduced to the ground distance between the two stations.

The basic physical requirements for shoran distance determinations are a knowledge of the velocity of radio waves, and a method of measuring the very minute time intervals involved in the travel of the radio waves from the plane to the ground stations and back. Electronic clocks which are used determine the time in microseconds. The clock dials on the shoran equipment are graduated to read in statute miles for convenience.

To date shoran work in triangulation has been accomplished with the instrumental equipment originally used for bombing missions with modifications made to effect improvements from time to time. No shoran equipment specifically designed for geodetic purposes has yet been manufactured. It is hoped that eventually electronic engineers can build an instrument which will give a timing accuracy of 10 ft; the fundamental principle of shoran is such that development to this high precision may be anticipated. If this accuracy can be obtained, then the resulting instrument will be capable of work comparable to first order triangulation.

In the computation and adjustment of shoran triangulation new procedures are required. Since the distances involved may be of the order of several hundred miles, the commonly used geodetic formulas for position, distance, and azimuth no longer apply. In addition, a new method of adjustment is required because the observed data comprise distances rather than horizontal directions.

Professor Chu presents one method for accomplishing the necessary computations and adjustment. His method differs from one developed by the United States Coast and Geodetic Survey, primarily because he uses Cartesian coordinates in space, rather than the more conventional latitude and longitude coordinates.

The theory of long-line geodetic computation is exhaustively treated in works of F. W. Bessel, F. R. Helmert, A. R. Clarke, and other geodosists of the nineteenth century. Their rigorous formulas have been utilized by the Coast and Geodetic Survey for shoran computation, after adaptation to modern calculating methods. The resulting computation system has proved convenient

and has the advantage of expressing the data in the same terms as those used in conventional triangulation. This consideration is important in cases where the old and new types of triangulation are intermixed.

The adjustment procedure is essentially the same for both systems, being based on the principle of the variation of coordinates. Observation equations are written, relating a small change in length of a line to corresponding small displacements of the stations joined by that line. Professor Chu expresses these displacements in terms of space coordinates whereas the Coast and Geodetic Survey method expresses them, with equal simplicity, in terms of latitude and longitude.

Since the shoran points must still lie on the reference ellipsoid after adjustment, the Chu method requires additional equations of the condition type. Although the general form of this type is illustrated by Eq. 8, there is no mention made as to how observation equations (see Eq. 6) and condition equations (see Eq. 8) are combined in a least-squares adjustment. A comprehensive treatment of this subject was presented by Joseph L. Stearn and Norman F. Braaten in 1948.[8]

The ultimate accuracy of the shoran method will depend on further experiments to determine the basic value for the velocity of the radio propagation wave and of radio path characteristics. Variations due to signal intensity are also troublesome and their control must be studied further. Additional research and development for electronic methods of distance determination are needed, and it is hoped ultimately to develop instruments and procedures which will produce results as accurate as those obtained in basic control networks by conventional optical methods.

[8] "A Method of Simultaneous Solution of a System of Observation and Condition Equations," by Joseph L. Stearn and Norman F. Braaten, *Transactions*, Am. Geophysical Union, April, 1948, pp. 157-162.

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DISCUSSIONS

FLEXURAL CONSTANTS OF HAUNCHED BEAMS BY AREA COMPUTATION

Discussion

BY GEORGE EPPS

GEORGE EPPS,[18] Assoc. M. ASCE.—The subject of beam constants, as used in various methods of analysis for statically indeterminate structures, has been discussed and presented from several different "angles." In fact, it seems that nearly everyone who has extensive use for these constants develops his own method for calculating them. Professor Tsai has presented an approach which, at first, seems to be rather complex; but after a little study it appears that it might be useful, particularly in problems involving fixed loadings.

In the design of bridges it is necessary to design for moving loads. Thus, fixed-end moments should be available for concentrated loads at several points. Most methods for deriving beam constants, including the author's, involve the use of partial moment areas for each position of the load. For this reason, the writer developed a method for determining such fixed-end moments which was presented in 1938.[19]

In the "Introduction," the author questions the accuracy of the trapezoidal rule of summation for use in the determination of beam constants. The writer has always used the rectangular rule, which is generally considered to be even less accurate, but he feels that the results obtained are sufficiently accurate for practical purposes. Many factors, such as cracking of the concrete, the effect of reinforcing steel, or the composition and connections of steel beams, all influence the beam constants. Various assumptions regarding these effects are made, which probably introduce errors much greater than any caused by the method of summation. Also, the actual loading on a beam seldom corresponds to the assumed or design load. This being so, it does not appear to be worthwhile to strive for great refinement in the calculation of beam constants. An indication of the comparative accuracy of various methods of summation is afforded

NOTE.—This paper by Fang-Yin Tsai was published in September, 1948, *Proceedings*. Discussion on this paper has appeared in *Proceedings*, as follows: December, 1948, by J. Edmund Fitzgerald, and Harris Solman; and February, 1949, by Robert V. Hauer.

[18] Bridge Engr., Secondary Roads Dept., Kansas State Highway Comm., Topeka, Kans.

[19] "Beam Constants for Continuous Trusses and Beams," by George Epps, *Transactions*, ASCE, Vol. 104, 1939, p. 1522.

by Table 2, which includes the momental areas for Example I as computed by the methods indicated. The difference between the correct values, as determined by integration (Col. 2, Table 2) and any of the others, is quite small.

The values of the momental areas in the paper are calculated for one end of the beam and those for the other end are found by differences in deriving the constants for the other end of the beam (as in Eq. 111*b*). The writer prefers separate computations for each end of the beam, thus making the differences noted previously available for checking purposes.

Professor Tsai develops beam constants for use in the distribution of angle changes and then converts them to the beam constants required for moment

TABLE 2.—COMPARATIVE ACCURACY OF METHODS OF COMPUTING MOMENTAL AREAS

Momental areas (1)	Integration (2)	Tsai (3)	Rectangular rule (4)	Trapezoidal rule (5)
A	0.7317	0.7318	0.7302	0.7339
A_1	0.4481	0.4482	0.4472	0.4498
A_2	0.3191	0.3192	0.3182	0.3203
A_3	0.2455	0.2455	0.2444	0.2452
A_4	0.1986	0.1985	0.1972	0.1989

distribution. All the designers with whom the writer is acquainted use the moment distribution or the slope deflection methods. For this reason, the author's method would be more useful if it were set up to give the required constants for these latter methods directly from the momental areas.

In the "Conclusion," Professor Tsai states that: "No separate M-diagram or M/I-diagram is needed for each loading, as is necessary in any of the existing methods." It appears to the writer that the momental areas in Eqs. 112 and 113 are areas of some M/I-diagram even though known by another name.

In general, it seems that the author's method is an attempt to produce a number of short cuts in the computation of beam constants through the use of the theorems of momental areas. This procedure should prove quite useful to one who is required to compute constants for a great many beams. For one who has use for such a calculation only occasionally it is believed that a simpler procedure might be more useful—such as, for example, an adaptation of the writer's procedure.[19]

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DISCUSSIONS

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EXPANSION JOINT PRACTICE IN HIGHWAY CONSTRUCTION

Discussion

By K. B. Woods, and J. K. Knoerle

K. B. Woods,[14] M. ASCE.—The subject of expansion joints in highway pavements has been treated in a timely and interesting manner by Mr. Anderson. The idea of restricting the use of expansion joints is a good one, and the writer is in general agreement with the conclusions drawn. However, the statement (see "Origins of Slab Stresses") that blowups are caused by infiltration of incompressible material in joints and cracks of concrete pavements is open to question.

In regard to pavements built without expansion joints, Mr. Anderson states, in the second paragraph under the heading, "Introduction," that:

> "Their major difficulty, which did not develop until after the pavement had been in service for five years or more, was a type of expansion failure commonly known as a 'blowup.'"

Also, under the heading, "Origins of Slab Stresses," he asks a question and answers it, thus:

> "What then causes compression failures, commonly known as blowups? * * * all evidence indicates that blowups are caused by a gradual loss of expansion space provided by crack or joint openings because of infiltration of incompressible material. This leads to the conclusion that blowups can be prevented by eliminating infiltration or reducing it to an insignificant amount. Much evidence shows this conclusion to be true."

Although infiltration is, no doubt, an important factor in causing blowups, as are certain combinations of temperature and moisture, it does not follow that infiltration of extraneous material is always a fundamental cause of blowups. Neither does it follow that all, old, nonjointed pavements blow up even though the crack interval may be long and may thus provide many large openings into which extraneous materials can infiltrate. Work done at Purdue University

Note.—This paper by A. A. Anderson was published in September, 1948, *Proceedings*. Discussion on this paper has appeared in *Proceedings*, as follows: December, 1948, by Frank H. Gardner.

[14] Associate Director, Joint Highway Research Project, and Prof. of Highway Eng., Purdue Univ., Lafayette, Ind.

(Lafayette, Ind.) in connection with extensive performance surveys throughout Indiana has shown that blowups should be correlated with the source of coarse aggregates used, at least for conditions prevailing in the State of Indiana.[15]

In this same work, field data were obtained from district offices covering the occurrence of blowups including time of day, age of pavement, prevailing weather conditions, location of the road with the failure, the location on the road with reference to grade and alinement, and materials incorporated in the pavement. Data were obtained and analyzed for a total of 517 blowups which occurred in the summers of 1940, 1941, and 1942. Precipitation and maximum temperature data were collected from the weather stations nearest to the road which contained the blowup. It was concluded that these blowups occurred predominantly in midafternoon at a temperature above 90° F—during a period which was usually preceded by varying amounts of precipitation. This analysis confirmed a report[16] published in 1925 to the effect that high temperatures following some precipitation appear to be the immediate causal factor in the occurrence of blowups. The infiltration of dirt into cracks, of course, would accentuate the difficulty by eliminating some of the otherwise available room for expansion.

The climatic and subgrade soil factors are further emphasized, in connection with an analysis of the causes of blowups, in a series of surveys made on three long road projects in Indiana, each of which was built on soils with a wide range of drainage characteristics.[17] These projects were all constructed with coarse aggregate materials of a less than average quality. However, detailed surveys showed that "mapcracking," which had previously been correlated with blowup susceptibility,[15] prevailed on those sections of each of the three projects that were constructed on relatively impervious soils. In contrast, those sections of all three projects which were built on well-drained sands, and, in one instance, on 18 in. of rock-flour silt, were relatively free from blowups and associated mapcracking. The susceptibility of certain types of pavements to blowups under certain conditions of temperature and moisture, and the correlation between blowups and mapcracking with materials used, as well as the drainage characteristics of the subgrade soils used, emphasize the materials-moisture-temperature-subgrade-soil variables rather than the infiltration-of-dirt-in-cracks-and-joints variable as causal factors. Furthermore, the importance of these variables raises the question in regard to the possibility of standardization of pavement design.

Since widely different materials and soil types are to be found throughout the United States, and since the nation is subjected to widely varying weather conditions (moisture and temperature), it is questionable as to whether or not such standardization could be accomplished with any degree of satisfaction for a unit as large as the entire country. A more logical engineering approach in regard to this problem might be that of standardizing designs by regions in

[15] "Pavement Blowups Correlated with Source of Coarse Aggregate," by K. B. Woods, H. S. Sweet, and T. E. Shelburne, *Proceedings*, Highway Research Board National Research Council, January, 1946, pp. 147–168.

[16] "Repair of Concrete Blowups in Delaware," *Engineering News-Record*, September 10, 1925, p. 432.

[17] "Mapcracking in Concrete Pavements As Influenced by Soil Textures," by H. S. Sweet and K. B. Woods, *Proceedings*, Highway Research Board, National Research Council, December, 1946, pp. 286–301.

which reasonably consistent types of materials, soils, climatic conditions, and even traffic conditions would prevail.

In addition to evaluating the moisture-temperature factors in studying blowups, a great quantity of data has been collected[15] on nonjointed pavements built before 1934 in Indiana. With similar conditions of age, soils, climate, and even traffic—within at least restricted locations—it still was found that some roads blew up while others did not. Detailed field checks were made on both types of pavement and information was collected in regard to construction materials and other factors that might have a bearing on the problem. These data were analyzed statistically and it was found that a significant correlation existed between the source of the coarse aggregate used in the concrete and pavement blowups. A total of 2,623 miles of pavements without joints was studied in this survey—2,404 blowups were recorded on 1,872 miles and 1,188 of these blowups occurred on only 284 miles of pavements constructed with coarse aggregates from only five different sources. Furthermore, 707 of the 1,188 blowups occurred on pavements built with one source of supply. In contrast, 851 miles of these nonjointed and old pavements contained no blowups. These data show that blowups occur in Indiana only on pavements constructed with certain types of aggregates, and that blowups do not occur on pavements constructed with certain other aggregates. To solve the problem, it would appear then that a determination of the characteristics of the materials which cause excessive expansion is required, rather than the adoption of designs which include such features as expansion joints. It is of interest to note that the State Highway Commission of Indiana has largely eliminated the use of expansion joints, as a concrete design feature, as a result of the data submitted in the research report on blowups.

As a result of the data obtained from the large-scale field performance surveys, a number of laboratory studies was initiated to determine the characteristics of the materials that were used in pavements susceptible to blowups as well as those which performed satisfactorily. In one laboratory study, Nung Yuen Lu[18] reported a number of interesting results including two which are pertinent to the discussion at hand: (*a*) The coefficient of expansion was different for different concretes and concrete materials when subjected to saturated, room-dry, and oven-dry conditions, and (*b*) concrete made with aggregates having good service performance records had a low coefficient of expansion whereas concrete made with aggregates having poor service performance records had a relatively high coefficient of expansion. However, it should be noted that, in this series of tests, the materials used had either extremely good or extremely bad service records. Thus, few data are available on the expansion characteristics of the materials with only average to moderately good service records. Furthermore, it is probable that this class of material is included in Mr. Anderson's materials with "normal expansion characteristics."

[18] "Comparison of the Thermal and Moisture Expansion of Concrete and Stone," by Nung Yuen Lu, a thesis submitted to the faculty of Purdue Univ. at Lafayette, Ind., in partial fulfilment of the requirements for the degree of Master of Science in Civil Engineering, in February, 1948.

At the same time, H. S. Sweet,[19] Jun. ASCE, was able to produce elongation, mapcracking, and ultimately complete failures, in beams made with coarse aggregates similar to those used in pavements that had an excessive number of blowups, by saturating the aggregate before incorporation in the concrete and then by freezing and thawing the beams. Similar procedures used on beams made with aggregates that had good service records produced no appreciable distress in concrete beams, even after several hundred cycles of freezing and thawing. Furthermore, Mr. Sweet was able to develop a method of identifying inferior aggregates which, when used in concrete, produced mapcracking and associated blowups.[20]

Messrs. Lu and Sweet were each able to produce deterioration in concrete beams made with inferior aggregates by subjecting beams, made by saturating the aggregate before incorporation in the concrete, to alternate cycles of both wetting and drying and heating and cooling.

In summary, the reports on Indiana field and laboratory data are in accord, in general, with Mr. Anderson's conclusion that expansion joints are not needed in modern highway pavements. However, interpretation of these data leads to the conclusion that blowups in these pavements are correlated, primarily, with the type of coarse aggregate and that certain combinations of temperature, moisture, loss of strength due to freezing and thawing, and types of subgrade soil contribute to this action. Although additional research is being conducted in connection with expansion and durability characteristics of various combinations of aggregates and cements, the data to date (January, 1949), including many field observations, indicate the need for standardization of design on a regional rather than on a national basis.

J. K. Knoerle,[21] M. ASCE.—A great contribution has been made by the author to the establishment of a uniform practice for expansion joint spacing in concrete pavement construction. The writer agrees with Mr. Anderson's recommendation for the elimination of expansion joints. Observations made on concrete pavements in many states indicate that such an approach coincides with actual findings. With respect to contraction joints, however, several additional factors have been encountered in practice which are not mentioned by Mr. Anderson.

The paper is based upon the use of "dummy contraction joints" spaced on 20-ft centers. Where mesh reinforcement is not used, such a practice appears to be the only alternative; however, the use of 264 man-made cracks per mile of pavement may prove to be undesirable in the long run. The pavement acts as a roof to shed water, and excess openings in this roof can only lead to future troubles for the following reasons:

1. Infiltration at the edges and bottom of the pavement slab may occur unless costly remedial waterproofing measures are provided. An accumulation

[19] "Concrete Durability As Affected by Coarse Aggregate," by H. S. Sweet, a thesis submitted to the faculty of Purdue Univ. at Lafayette, Ind., in partial fulfilment of the requirements for the degree of Doctor of Philosophy in June, 1948.

[20] "Research on Concrete Durability As Affected by Coarse Aggregate," by H. S. Sweet, paper presented at the Annual Meeting, Am. Soc. for Testing Materials, Detroit, Mich., June, 1948 (publication pending).

[21] Senior Associate, J. E. Greiner Co., Cons. Engrs., Baltimore, Md.

of foreign matter may result in differential movements of individual slabs causing wider openings at some joints and possibly blowups at others.

2. In cutting the pavement for the placement of dummy joints, it is necessary to disturb the smooth concrete surface which has been properly consolidated and screened by the finishing machine. The concrete aggregate becomes displaced or rearranged and excess mortar is floated to the surface.

3. Closely spaced joints require extra maintenance per mile of highway with the possibility of leakage and pumping under certain conditions.

4. Each joint increases pavement roughness because of the difficulty in "straightedging" a smooth surface after cutting the joint.

5. Where doweled contraction joints are used, there is always the danger of misalinement which may cause eccentric loading and cracks in the pavement. The more joints the greater will be the danger of uncontrolled cracks due to this hazard.

6. The assurance that the pavement will carry heavy loads over a long period of years with a minimum of interference to traffic is reduced by increasing the number of joints.

Where reinforcement is used in paving slabs, it has been found that contraction joints spaced from 46.5 ft to 61.5 ft on centers produce the most economical combination on the basis of the in-place cost of the joint material and the pavement reinforcement. A reinforced pavement with contraction joints spaced up to 61.5 ft on centers should be three times as sound as a nonreinforced pavement with joints spaced 20 ft on centers. The danger of joint failures and pumping, with resulting high maintenance costs, is reduced to one third. The new rubber type of joint filling compounds possess satisfactory waterproofing characteristics; therefore, joints sealed with this material and spaced 61.5 ft on centers should perform equally as well as joints spaced 20 ft on centers.

The main difficulty with contraction joints today is the need for a satisfactory load-transfer device that can be set accurately and that will function properly during the life of the pavement.

The trend in recent years is toward the elimination of joints, which have proved to be the chief source of pavement troubles. The states of New Jersey and Illinois are experimenting with heavily reinforced pavements poured continuously without either expansion or contraction joints. Such a design appears to be a step in the right direction and the results of those tests will be watched with interest by all highway engineers.

Mr. Anderson's paper has brought forth some interesting data and it is hoped that within the next few years highway engineers will agree upon a standard joint practice to simplify design, construction, and maintenance, thereby prolonging the life and improving the riding quality of concrete pavements.

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DISCUSSIONS

REVIEW OF SLOPE PROTECTION METHODS

REPORT OF THE SUBCOMMITTEE ON SLOPE PROTECTION OF THE COMMITTEE ON EARTH DAMS OF THE SOIL MECHANICS AND FOUNDATIONS DIVISION

Discussion

BY JULIAN H. WHITE, AND CHARLES SENOUR AND HANS KRAMER

JULIAN H. WHITE,[43] Assoc. M. ASCE.—A problem so complex as slope protection design will probably continue to be approached by empirical methods. A basis for design and for correlating successful installations has been made more generally available in the subcommittee report.

Since it is recognized (under the heading, "Destructive Forces That Act on Embankment Slopes") that: "The principal destructive force that acts on the water face of an earth dam is that due to wave action," some knowledge of the wave itself is essential. However, the writer believes that the fundamentals of waves are so much better known than are the mechanics of the wave action on slope protection that more emphasis should be placed on the latter.

The magnitude of the force of impact of waves on riprap is one of the uncertain factors. The statement in the report (under the heading, "Destructive Forces That Act on Embankment Slopes") that—

> "It follows that the force a wave exerts on riprap stones on the face of a dam cannot be greater than that of a current flowing at a velocity equal to the velocity of the water particles of the wave."

does not, in the opinion of the writer, follow from the acceptance of the conclusions of D. D. Gaillard, as quoted in the report. In the case of waves breaking against the riprap, the conditions of submergence and continuity of flow, on which Captain Gaillard's conclusions appear to be predicated, do not obtain. The phenomena under most severe circumstances, the writer believes, more nearly resemble those of elastic impact such as in water hammer.

NOTE.—This report was published in June, 1948, *Proceedings*. Discussion on this report has appeared in *Proceedings*, as follows: October, 1948, by Howard J. Hansen, William P. Creager, Henry H. Jewell, Joe W. Johnson, and Martin A. Mason; December, 1948, by R. M. McCrone, and Harold Weggel; and January, 1949, by Walter F. Emmons and Adolf A. Meyer.

[43] West Concord, Mass.

If, as an extreme example under this assumption, a wave moving with a vertical face were to strike the parallel vertical face of a piece of riprap, there would be no continuity of water, and the regimen of flow associated with a current passing a submerged object would not have become established. Instead the two vertical faces would come together with sudden impact, and the forward velocity of the water at the face would be instantly arrested. There would result a compression of the water beginning at the surface of contact and traveling upstream with the velocity of an acoustic wave, similar to water-hammer phenomena in a pipe. Here, unlike the condition in a pipe, there would be no wall to prevent the release of the compression by lateral expansion. The only confining effect would be the resistance to any change in motion in a lateral direction caused by the inertia of the adjacent mass of water forming the wave. The compression phase would therefore last only for the time required for an elastic wave of relief pressure to reach the point under consideration.

Following the assumptions of water-hammer action further, the pressure rise created by sudden arrest is dependent solely on the velocity change. With a wave having a velocity retardation of 5 ft per sec, the pressure developed would be well over 200 lb per sq in. The magnitude of this pressure is far greater than that of any pressure arising from ordinary current action. In addition to the direct action of this large elastic force on the riprap, there would be the concurrent hydrostatic excess pressures in the cracks and joints with the resulting high velocities. Under the assumptions, the time during which these forces acted until they were relieved would be very small in most cases, but it is conceivable that it could have considerable effect on the stability of the riprap.

The occurrence of these phenomena and their importance to the whole problem of slope protection can be shown only by experiments that explore more fully the mechanics of wave action on riprap.

CHARLES SENOUR[44] and HANS KRAMER,[45] MEMBERS, ASCE.—The report of the Subcommittee on Slope Protection presents an excellent coverage of the analytical aspects of the problem. Its value would have been greatly enhanced, however, by a broader survey of the applicatory aspects based on a comprehensive inventory and evaluation of the many cases of existing slope protection that are practical monuments of either success or failure. Such an evaluation would necessarily have to include the economics of slope protection, both as to first cost and as to upkeep.

The Corps of Engineers is not only contemplating wave tank tests to check theories on riprap design but is making (1949) a series of full-size experimental installations at Grenada Reservoir in Mississippi to obtain reliable data on the behavior of conventional riprap and various substitute treatments under identical conditions of exposure. This discussion is intended primarily to augment the report of the subcommittee in respect to the full-size tests at Grenada,

[44] Chf. Eng. Asst., Mississippi River Comm., Vicksburg, Miss.

[45] Brig.-Gen., U. S. Army (*Retired*), Cons. Engr., San Francisco, Calif.

particularly those involving articulated concrete armor of the type that has proved highly effective in protecting the friable banks of the Mississippi River.

Slope Protection for Earth Dams.—The considerable distances that stone riprap must be transported to projects in the lower alluvial valley of the Mississippi River make its use quite expensive. However, although dumped riprap has been placed on the earth and hydraulic fill dams hitherto built in northern Mississippi and has been prescribed for two earth fill dams now (1949) under construction there, experiments with other types of protection are to be undertaken in the near future. Although the experiment will include several types of protective covering, it was initially conceived to explore the possibilities in connection with wave wash protection, of the standard articulated concrete revetment so widely used for the prevention of bank caving on the lower Mississippi River.[46]

As employed for the latter purpose, the part of the revetment extending from the top of the river bank to the low water line, in some locations is subjected not only to current velocities of as much as 15 ft per sec but also to prolonged wave attack as well as battering from heavy drift. The fetch is seldom more than 5 or 6 miles and the wave approach is usually diagonal. No instances are known where the revetment has failed by wave action. The sandy bank, often 40 ft or so above low water line, is usually graded to a slope of 1 on 3 and covered with a 4-in. blanket of river-run gravel on which the articulated mattress units are placed.

Large quantities of articulated mattress are used on the lower Mississippi and mass production methods hold the cost of manufacture to about 12.5¢ per sq ft. In place on the upper bank the cost, exclusive of grading and filter, is about 27¢ per sq ft. The mattress units are laid upon the bank slope with the 25-ft dimension normal to the water edge, and frequently the openings between contiguous units are later filled with concrete grout or asphalt mastic.

From the standpoint of wave wash protection an articulated concrete mattress appears to offer several advantages. It is cheaper than riprap in localities distant from suitable stone supply, yet avoids the drainage problems and lack of adjustability which seem to be the chief deterrents to the use of monolithic concrete. Such a mattress could scarcely be damaged by uplift pressures even if it were possible for these to develop as in the case of monolithic concrete or large slabs, because local relief could be secured by local uplift without disturbing the integrity of the mattress as a whole—nor has fatigue of the reinforcement or connections been detected in more than 30 years of use on the river. Under conditions of its employment on the river, it does not require anchorage to prevent creep down the slope. Under the action of higher waves and steeper slopes occasional anchorage conceivably might be desirable. It might likewise prove desirable to place two layers of mattress with all joints staggered, and possibly to omit or to reduce the gravel filter as a partial offset to the increase in cost entailed by the double thickness.

Although the capacity of the articulated mattress to protect the river banks against both current and wave attack has been impressive, it has been felt that

[46] "New Project for Stabilizing and Deepening Lower Mississippi River," by Charles Senour, *Transactions*, ASCE, Vol. 112, 1947, pp. 277–290.

reliance on it for protecting the upstream slopes of high earth dams should await the results of an actual trial under the somewhat different conditions to which such use would expose it. The setting for such a trial is provided by a sloping headland near the Grenada reservoir spillway approach channel which will require only a small amount of grading to prepare it for the reception of experimental paving and which will provide exposure conditions almost identical with those of the dam itself. The fetch measured at conservation pool elevation of 193 ft above mean sea level will be about 7 miles.

It is planned to install in this area several arrangements of articulated concrete mattress, a section of monolithic concrete, and a section of riprap lighter than that used on the dam. The riprap on the dam is 30 in. thick on a 12-in. gravel filter; and it costs \$7.27 per cu yd, or \$6.06 per sq yd exclusive of filter.

For the purpose of comparative tests, it is proposed to install five 48-ft strips of articulated mattress (twelve units wide) in the test area, side by side on the prepared slope and extending from the flood control pool elevation (El. 231) down to El. 190, which is 3 ft below the conservation pool elevation. Two of the strips would consist of a single thickness of mattress on a 12-in. gravel filter, the sole difference between the two being that for one strip, all joints normal to the water edge would be grouted and for the other, all joints would be left open. The other three strips would consist of a double layer of mattress. One of these strips would be placed on the graded slope directly, without gravel filter, and would have the joints normal to the water edge grouted. The remaining two strips would have 12-in gravel filters under them, one with and one without grouted joints.

The monolithic concrete pavement proposed to be installed in the test area would be 6 in. thick and 50 feet wide, with anchorage to a 3-ft wall to be embedded in the slope at the elevation of the flood control pool. This method of restraint is proposed to permit adjustment of the slab during expansion. The design contemplates a gravel filter and drainage through the slab. It is proposed to reinforce the slab by using $\frac{3}{4}$-in.-round bars, 12 in. center to center each way, placed at the center of the slab.

The light riprap section would also be 50 ft wide over the same slope distance, and would be composed of dumped riprap 12 in. thick placed on a gravel filter.

It is planned to make auger borings of the test area after grading has been completed and before filter material or revetment has been placed. In determining the spacing of the borings, each 48-ft and 50-ft experimental section will be divided into approximately three equal areas and a boring made at about the center of each area. A field classification will be made of each boring. Borings will be about 10 ft deep.

Records of construction costs, broken down to indicate the cost of each major element, will be carefully kept. Restoration costs will also be noted where such operations are considered to be beyond normal maintenance.

When completed, the installation will be observed periodically and also after periods of strong wave action to ascertain comparative effectiveness. These observations will include:

(*a*) Durability of the basic mattress material under wave action and weathering;
(*b*) Durability of wires in articulated concrete mattress;
(*c*) Stability of riprap and its effectiveness in preventing removal of filter material under wave action;
(*d*) Effectiveness of articulated concrete mattress with open joints in preventing removal of filter material, and durability of grouted joints;
(*e*) Notation of cracks in the monolithic concrete and description of progressive development of the cracks;
(*f*) Apparent effectiveness of drainage through the monolithic pavement; and
(*g*) Photographs showing the general condition of the sections taken periodically at fixed stations.

(Detailed photographs will be taken of all failures or points of material deterioration, at such intervals as to indicate the progress of such deterioration or failure.) It is further proposed that wind velocities and wave heights near the center of the installation will be determined by a recording anemometer and a wave height recorder.

Recently, the banks of the lower Mississippi River above the low water line and several exposed levee slopes have been protected by a 5-in. to 6-in. coating of a hot mix consisting of river-run sand and about 6%, by weight, of asphalt cement. The mix is applied directly upon the graded slope at temperatures of from 225°F to 350°F from trucks or clamshell buckets and is screeded or raked to an even thickness without compaction. It is porous enough to permit bleeding of the ground water yet heavy enough to protect the slope against the onslaughts of current and waves and heavy drift. It costs, in place on the bank slope, about 26¢ per sq ft. It is hoped that the Grenada experiment can be expanded to include a section of sand-asphalt mix.

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DISCUSSIONS

DULUTH-SUPERIOR HARBOR

Discussion

By Harland C. Woods

Harland C. Woods,[3] M. ASCE.—In addition to the inconsistency noted by Colonel Cole in the tonnage data for New York (N. Y.) harbor, there is another tonnage given in this paper that is misleading as quoted. In the list of five important ports of the United States, San Francisco Bay in California is credited with an annual tonnage of 32,200,000 for the year 1945. That amount includes duplications of intraport shipments and is for all the ports in the San Francisco Bay area. Adjustment by one half of the total intraport receipts and shipments reduces it to 26,100,000, and restricting it to San Francisco and the near-by harbors of Oakland and Richmond reduces it to 18,200,000 tons. Tabulating all the ports of the United States having 1945 adjusted commerce of more than 5,000,000 tons, and crediting to each the tonnage through localities closely contiguous to the name harbor, gives the values listed under 1925 in Table 1.

TABLE 1.—Comparison of Annual Cargo Tonnages

Harbor	1925		1946	
	Million short tons	Descending order	Million short tons	Descending order
New York, N. Y.	78.8	1	82.1	1
Duluth, Minn., and Superior, Wis.	65.4	2	54.2	2
Toledo, Ohio	30.5	3	30.0	6
Buffalo, N. Y.	27.1	4	16.5	14
Philadelphia, Pa.	26.1	5	32.7	4
New Orleans, La.	25.2	6	29.8	7
Houston, Tex.	23.8	7	31.8	5
Los Angeles, Calif.	23.8	8	14.4	18
Baltimore, Md.	23.1	9	34.7	3
Galveston, Tex.	22.5	10	6.8	28
Chicago, Ill.	20.2	11	19.0	11
Two Harbors, Minn.	19.7	12	15.6	16
Cleveland, Ohio	18.6	13	16.5	15
San Francisco Bay, California	18.2	14	17.0	13
Detroit, Mich.	16.0	15	28.0	8
Norfolk, Va.	14.4	16	18.3	12
Conneaut, Ohio	14.0	17	11.9	21
Beaumont, Tex.	13.6	18	23.0	9
Sandusky, Ohio	13.5	19	12.6	19
Ashtabula, Ohio	13.0	20	12.1	20
Indiana Harbor, Ind.	13.0	21	11.2	22
Boston, Mass.	12.8	22	15.0	17
Port Arthur, Tex.	12.2	23	20.1	10
Gary, Ind.	10.5	24	8.6	26
Portland, Ore.	10.5	25	9.3	24
Seattle, Wash.	10.2	26	10.4	23
Calcite, Mich.	9.7	27	....	....
Lorain, Ohio	9.7	28	8.6	25
Erie, Pa.	9.1	29	5.9	31
Milwaukee, Wis.	8.0	30	7.9	27
Escanaba, Mich.	5.5	31	....	....
Ashland, Wis.	5.4	32	....	....
Mobile, Ala.	....	....	6.2	29
Portland, Me.	....	....	5.9	30

Of the thirty-two harbors listed, eighteen are Great Lakes ports, five are Atlantic Coast

Note.—This paper by Heston R. Cole was published in November, 1948, *Proceedings*.

[3] Prin. Engr., Buffalo Dist., Corps of Engrs., Dept. of the Army, Buffalo, N. Y.

ports, five are Gulf Coast ports, and three are Pacific Coast ports. The magnitude of the Great Lakes commerce is further indicated by the data in Table 2 from the annual report of the Chief of Engineers, United States Army, for 1945 commerce.

TABLE 2.—RELATIVE ANNUAL CARGO TONNAGE (MILLION SHORT TONS) ON VARIOUS COASTS

Coast	1925		1946	
	Million short tons	Order	Million short tons	Order
Great Lakes	357.0	1	314.5	2
Atlantic	287.1	2	326.1	1
Gulf	135.6	3	174.7	3
Pacific	123.7	4	104.8	4

In 1945 traffic had not fully recovered from the war dislocation, as will be noted in the 1946 column of Table 1, which illustrates the changes through readjustment of traffic.

Of the thirty-one ports then having an annual tonnage in excess of 5,000,000, fifteen are on the Great Lakes, five are on the Atlantic Coast, six are on the Gulf Coast, and four are on the Pacific Coast (see 1946 data in Table 2). Tonnage at some Great Lakes ports declined largely because of reduced quantities of iron ore and limestone used in war production. That at the Gulf Coast ports increased (some very greatly) through increased shipments of oil and oil products.

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DISCUSSIONS

DYNAMIC INSTABILITY OF TRUSS-STIFFENED SUSPENSION BRIDGES UNDER WIND ACTION

Discussion

By A. G. Pugsley, and S. K. Ghaswala

A. G. Pugsley,[13] Assoc. M. ASCE.—This interesting attempt to link the suspension bridge flutter problem with the extensive knowledge of flutter already developed by aeronautical workers is very welcome. However, it is regrettable that the author has so wholeheartedly adopted the mathematical presentation customary among analysts of airplane flutter in the United States, rather than taken advantage of the simpler modes of presentation that have always been usual in England. Any sound simplification at this stage seems especially advantageous, as the aim presumably is to interest and guide practicing civil and structural engineers who have none of the flutter background that is relatively common among aeronautical engineers.

Eqs. 1 and 2 express the lift and moment on a plate in terms of the torsional and "flexural" coordinates, ϕ and $\bar{\eta}$, as given by a particular vortex theory commonly associated with T. Theodorsen in the United States, and with H. Glauert[14] and W. J. Duncan in England. Regardless of the theory (or experimental background) used, however, the lift and moment can still be expressed simply in terms of the coordinates ϕ and $\bar{\eta}$, thus:

$$F_L = a_1 \phi + b_1 \dot{\phi} + c_1 \ddot{\phi} + d_1 \bar{\eta} + e_1 \dot{\bar{\eta}} + f_1 \ddot{\bar{\eta}} \ldots\ldots\ldots\ldots (99)$$

and

$$M_L = a_2 \phi + b_2 \ddot{\phi} + c_2 \dot{\phi} + d_2 \bar{\eta} + e_2 \dot{\bar{\eta}} + f_2 \ddot{\bar{\eta}} \ldots\ldots\ldots\ldots (100)$$

in which the coefficients a_1 to f_1 and a_2 to f_2 (some may be zero) are approximately constant and may be based on the best available theory or experiment. This type of presentation would reduce the length of algebra without detracting from the theory of flutter, and would be independent of a particular derivation of such coefficients as a_1, b_1, etc. This is an English criticism of much American

Note.—This paper by Friedrich Bleich was published in October, 1948, *Proceedings*.

[13] Prof., Civ. Eng., Univ. of Bristol, Bristol, England.

[14] "The Force and Moment on an Oscillating Aerofoil," by H. Glauert, Aeronautical Research Committee, *Reports and Memoranda No. 1242*, H.M. Stationery Office, London, 1929.

work on flutter in general; the custom in the United States appears to have been started by Mr. Theodorsen at a time when he was very interested in vortex theory and was practically the only worker on the subject of flutter in the United States.

The writer is particularly anxious that this suspension bridge problem should not be obscured and made unnecessarily difficult at this stage to civil engineers generally. In place of too much theory, therefore, he would advocate even an oversimplification, and to illustrate this offers the following comments.

The writer agrees with the author's main thesis—that in the suspension bridge problem there are probably two main types of flutter: One is the classical flutter which is typical of airplane wing flutter and involves essentially the coupling of at least two degrees of freedom—in the bridge case, vertical and torsional motions—and the other arises from forces caused by the eddies shed by the bridge—primarily from its bluff "leading edge." The first type of flutter has a critical speed, as indicated by the author, which is essentially a function of the elastic, inertial, and aerodynamic characteristics of the bridge, whereas the second is of the nature of the "galloping" of telegraph wires and is comparable with what English workers in the field (having in mind the buffets from the shed eddies) have called "auto-buffeting." In the first case the amplitude of motion may rapidly become excessive at speeds greater than the critical. The amplitude of motion in the second case becomes appreciable only when the eddies are fairly large and shed at regular intervals at a frequency approximating a natural frequency of the bridge structure. It is thus understandable that such oscillations occur at the natural frequencies of the bridge and are most pronounced for decks with side girders having continuous plate webs.[15]

The possible remedies for the two types of flutter are quite different. The occurrence of classical flutter can be postponed to higher and higher speeds by increasing the torsional stiffness, and by what aeronautical workers call "mass balancing," which aims at removing any coupling between the torsional and vertical motions of the deck. These steps have little effect on any resonance between the shed eddy frequency and the natural frequency (for vertical or torsional motion of the deck). The remedy for the resonance is to break up, both in space and in regularity, the eddies shed by the "leading" deck girder—for example, by changing from a plate web to an irregular lattice web.

From what the writer has seen of suspension bridge flutter in wind tunnel model work, it seems that most of the "critical speeds" observed may be attributed primarily to eddy resonance, the particular speed itself arising from the fact that in a given case eddy frequency varies with wind speed and thus "picks up" in succession the natural frequencies of the structure. (The latter are mostly flexural in the lower ranges.) Only occasionally will one of the critical speeds derive from coupled conditions associated with classical flutter.

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[15] "An Experimental Investigation of the Aerodynamic Stability of Suspension Bridges," by C. Scruton, 3d Cong. of the International Assn. for Bridge and Structural Eng., Zurich, 1948.

It is with the foregoing thoughts in mind—no doubt an oversimplification of the physics of the problem, yet a useful one—that the writer expresses regret for the detailed mathematics which the author chose as his vehicle. Such treatment also may inadvertently present an appearance of greater accuracy than is possible. There is little doubt, for example, that the vortex theory behind Eqs. 1 and 2 (which may be appreciably in error even for simple airfoils) can be only a rough guide for the complex shapes presented by bridge decks. Nevertheless, the application of aeronautical flutter theory that this paper presents is very welcome.

S. K. GHASWALA,[16] JUN. ASCE.—An interesting mathematical analysis of the stability of suspension bridges under wind action is given in this paper. Considerations for a comprehensive study of these problems will necessarily include (1) the question of the damping capacity of the bridge; (2) a study of the winds as they exist in nature, especially the meteorological aspects; and (3) model tests in wind tunnels involving the coordination of the model and prototype and scale effect on the Reynolds number when turbulent flow is involved.[17] No discussion of this subject is complete without reference to the pioneering work of D. B. Steinman,[18] M. ASCE. Dr. Steinman appears to be the first to have developed simple formulas for determining the aerodynamic stability of suspension bridges. In fact his equation,

$$E_f\, I'_f > \frac{b\, L^4}{60\, \sqrt{h}} \qquad (101)$$

represents a simple criterion for determining the dividing line between aerodynamically stable and unstable sections.[19] In the relation, Eq. 101, E_f is the modulus of elasticity of the stiffening girder; I'_f is the moment of inertia of the half section of one stiffening girder; b is the half width of the section between center lines of the cables; L is the length of span; and h is the vertical cable sag.

In the normally required range of wind velocities, any suspension bridge with a stiffening system, satisfying Eq. 101, will be aerodynamically stable. When proportioned below this requirement it becomes unstable.

It is true that in the light of present knowledge the development of a design that would be structurally and aerodynamically stable, and at the same time the most economical, would be most difficult. The problem now facing engineers (after the collapse of the Tacoma Narrows Bridge) is without precedent in engineering history for the major part of preliminary designing falls into the field of aeronautics and aeronautical meteorology as stressed by the writer elsewhere.[20]

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[16] Designing Engr., Concrete Constr. and Eng. Co., Ltd., Bombay, India.

[17] "Wind Tunnels," by S. K. Ghaswala, *Science and Culture*, December, 1943, p. 224.

[18] "Rigidity and Aerodynamic Stability of Suspension Bridges," by D. B. Steinman, *Transactions*, ASCE, Vol. 110, 1945, p. 439.

[19] *Ibid.*, p. 575.

[20] "The Role of Meteorology in Civil Engineering," by S. K. Ghaswala, *Civil Engineering and Public Works Review*, London (publication pending).

The Tacoma Narrows Bridge was by far the most flexible and most economical bridge of comparable span. Had it been aerodynamically stable it would have represented great progress in bridge design and construction. In fact, it is the writer's belief that, once the aerodynamic theory of suspension bridges is thoroughly understood and verified by model tests, it may be possible to build bridges even more flexible and economical that this ill-fated structure. This paper appears to go a long way toward the realization of this goal and toward a deeper understanding of the laws of dynamics and their application to bridge design.

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DISCUSSIONS

PANAMA CANAL—THE SEA-LEVEL PROJECT
A SYMPOSIUM

Discussion

By H. H. Little, and A. Casagrande

H. H. Little.[129]—Much was written, in the paper by Colonel Stratton, about the "capacity" of the Panama Canal. What does that term mean? Great stress is laid on "time of transit." To avoid the creation of exaggerated impressions as to their importance, the relation of the terms, "capacity" and "time of transit," to the broad field of strategic planning should be explained by the author, in his closing discussion.

In regard to "capacity," very little in the way of factual analysis has been published on the actual "capacity" of the Panama Canal as it now exists. Messrs. Johnson and Steinborn report (see "Capacity of the Present Panama Canal: Dependable Daily Capacity of Present Canal"): "* * * the dependable daily capacity of the existing canal is taken at its minimum daily capacity during overhaul—or 36 vessels." This would be a minimum of 13,140 ships a year. Colonel Stratton reports (under "Traffic History of the Canal") that there were nearly 17,000 transits of war traffic through the canal from 1941 to 1945. Assuming that this period includes 4 years, the average yearly transit was 4,250 ships, which would indicate that, during World War II, the present canal was operated for war traffic to only about 30% of its minimum capacity.

Under "The Panama Canal As It Is Today," Colonel Stratton states:

> "* * * It is estimated that by about 1960 the capacity of the canal will be inadequate to accommodate traffic without inflicting undesirable delays on peak traffic days."

In other words, the canal is not to be used to "capacity" at other times, but by 1960 it will be used to "capacity" only on "peak traffic days." What does

Note.—This Symposium was published in April, 1948, *Proceedings*. Discussion on this Symposium has appeared in *Proceedings*, as follows: June, 1948, by Hans Kramer, and Philip G. Nichols; September, 1948, by George B. Pillsbury, Kenneth S. M. Davidson, Joel D. Justin, W. H. McAlpine, W. E. R. Covell, William Herbert Hobbs, Hibbert Hill, Kenneth C. Reynolds, Gregory P. Tschebotarioff, Charles W. Dohn, and Donald F. Horton; October, 1948, by E. Montford Fucik, Charles M. Romanowitz, and Raphael G. Kazmann; November, 1948, by George B. Massey, William Allan, and Boris A. Bakhmeteff; December, 1948, by Robert C. Sheldon, F. W. Edwards, and H. R. Cedergren; January, 1949, by Harry O. Cole, Ole P. Erickson, Clarence S. Jarvis, Anson Marston, and Ralph Z. Kirkpatrick; and February, 1949, by Ernest Shankland, and John S. McNown.

[129] Capt., U. S. Navy (*Retired*), St. Margarets, Annapolis, Md.

industry do when confronted with similar problems of "peak traffic"? They control them! It spreads the load by proper planning; and, if need be, it increases charges for "peak" business, peak electric rates, peak labor costs, peak charges of any description. Has any attempt been made to control peak traffic at the canal? None is mentioned in the Symposium. There should be many ways of controlling sailings to, or arrivals at, Panama and also of removing bottlenecks in the canal so that traffic will not jam on peak days. Certainly no canal could be built which would prevent occasional peak loads when no attempt is made to control traffic or improve its functioning. The obvious answers to the question are the control of traffic and the proper modification of the present canal, not building canals at other locations across the Isthmus or attempting the construction of a new sea-level Panama canal.

As for "time of transit," it should be realized that plans for military operations are prepared far in advance of the dates of embarkation. Personnel, supplies, and ships are calculated, checked, and rechecked dozens of times. Material is ordered, manufactured, shipped, and stored weeks and even months in advance; D-day is never set until the required resources are on hand and allowance is made for shortages—material which would not arrive because of sinkings, bombings, or failure to load. No general or admiral ever had to "tear his hair out" because some ship or convoy of ships was late in passing through the Panama Canal. Although the expeditious handling of vessels at Panama (or anywhere else) is expected as normal performance, it is doubtful if any saving in time at the canal ever had any bearing on the outcome of an important military undertaking.

Colonel Stratton's repeated use of the term "security" deserves to be properly analyzed or circumscribed in his closing discussion. The writer was startled by the statement in the "Synopsis" that:

> "A sea-level canal at Panama constructed by the conversion of the existing lock canal could not be destroyed by enemy attack or sabotage. Only the atomic bomb could cause significant interruption in service, and then for not more than a few weeks."

A statement such as this can be misleading without essential amplification. As a major premise it represents the greatest weakness in the attempt to justify the sea-level proposal. The statement is true, of course, in the sense that earth and water cannot be destroyed, but it is not true in the sense that the damage caused to a sea-level canal, even by conventional weapons, would be insignificant. A bomb or a thousand bombs dropped in the Mojave Desert in California would have no effect in destroying the desert, but determined bombing attacks or sabotage on the many miles of proposed impounding dams, spillways, tidal locks, and other structures of the Panama Canal (which are shown in Fig. 11 to be necessary for the control of the floodwaters of the Chagres River Valley and for the regulation of tidal currents in a sea-level canal) would create almost incalculable problems and would make the canal unnavigable for long periods. These dangers together with the greater structural damage and channel closures that may be caused by atomic bombs should be just as effective militarily in interrupting ship transit as would be the draining of Gatun Lake.

From the evidence presented in the Symposium it seems questionable if the vulnerability of the many flood-control installations and of the other massive structures in the sea-level plan was explored as it should have been. Until such an exploration is made, the question of which type of canal has the "maximum security" against atomic bombing appears to be one for theoretical discussions and not for practical planning, because no amount of static defense measures can give a real "security" to any type of canal.

Conversion of the existing lock canal (see "Synopsis") is another term that needs a more complete analysis. With the exception of the channel sections near the ends of the present canal the plans outlined by Colonel Stratton envisage an entirely new canal with the greater part located at varying distances from the present canal. This feature, because it does not conform to canal treaties, introduces a great international political question that would require complicated negotiations for a new treaty with the Republic of Panama and the payment of a huge indemnity and an increased annual subsidy by the United States government. In view of the rejection of the Defense Base Treaty by Panama in 1948, the negotiation of a new canal treaty no doubt would present even more serious difficulties. This important subject might well be included in the Symposium. Certainly any cost estimate should make some provision for the costs that would be encountered in this connection, in order to justify, fully, the ultimate cost of the sea-level project.

Much might be offered in comment on that part of Public Law No. 280 which Colonel Stratton quotes in his "Introduction." For example, it is fair to question whether passage of this act really "expressed the temper of present concern" of the Congress rather than the ideas of those proponents who were determined on a sea-level revision. Regarding "increasing the capacity" it might be asked whether the sea-level project if built would work better than the present canal—an important phase not covered in the Symposium.

Again, regarding the law's reference to "Canals at Other Locations," it should be remembered that the Nicaragua and other canal routes have always had large followings which had to be given some hope or the bill would not have passed Congress. In other words, it was a foregone conclusion that no scheme other than a sea-level canal at Panama would receive any real consideration under the act.

Colonel Stratton states (under the heading, "The Panama Canal As It Is Today") that:

> "The restricting effect of the small locks (width 110 ft, length 1,000 ft) of the present canal on the design of Navy ships became intolerable with the approach of war * * *."

As far as has been ascertained the Navy has made no strong demands; nor has it indicated that the present conditions were "intolerable." The *U.S.S. Missouri*, the latest type and only first-line battleship in active use, successfully transits the present canal. All the others are in "moth balls," peacefully awaiting "overage" status. These include the older battleships, which were modified by the installation of buoyancy blisters on their sides, thus increasing their beams beyond the capacity of the 110-ft locks.

Naval strategy, however, does look ahead. Should it appear that the wider ships are needed on the opposite coast it would be no great hardship for these vessels to round Cape Horn. They carry sufficient oil for the full trip, coast to coast. Note well that this refers to the largest combatant ships, for there never has been any question about the adequacy of the present canal for the transit of commercial ships.

If the world situation ever requires a precautionary redistribution of United States naval forces, the largest vessels could be sent around South America with the utmost secrecy. There can be no secrecy once vessels are seen in the Canal Zone. As some of the larger aircraft carriers and three older decommissioned battleships are the only war vessels that cannot now transit the canal, the situation would appear far from "intolerable" from the naval standpoint.

It is true that the Navy asked for locks 140 ft wide for the Third Locks Project. It also recommended locks 200 ft wide as a beginning for the recent studies. These naval statements must have been in the form of guarded replies to specific inquiries from canal authorities rather than as strongly worded recommendations for the 200-ft locks. As a leading question, how many times a year would the larger carriers or oversize battleships use the canal if it could accommodate them? The answer is probably not once in 2 years.

Next, how about the navigational safety of a sea-level canal? The related statements in the Stratton paper, based largely on ship model tests, are assumptions and not established facts. In this connection, also, further elaboration is requested to support the incomplete facts presented. In the unregulated sea-level canal, with currents as much as 4.5 knots, an element of great danger that cannot be minimized is immediately introduced. In the regulated sea-level canal the much increased length of restricted channel and the ordinary problems of navigation—night fog, heavy rains, and machinery failures—do not seem to have received the consideration that is due them. To the writer it seems obvious that the lake-type canal with its wide current-free channels is far better adapted to safe navigation than any necessarily restricted sea-level canal at Panama can ever be.

In the "Synopsis" and under "Improvements in the Interests of Commerce Only," Colonel Stratton states that with new navigational aids and other minor changes the present canal could be improved sufficiently to accommodate the transit of 70 ships a day at a cost of $129,983,000. The sea-level canal as projected, estimated as costing $2,483,000,000, he states, would transit 69 ships. This comparison indicates that the Symposium authors are recommending something that will cost twenty times as much as improvements in the present canal and that the completed works will not be as efficient.

In their closing discussions the Symposium authors need to balance the presentation with an adequate treatment of the present operational deficiencies long recognized by all maritime agencies that use the canal. These are such that the proposed minimum improvement program ($129,983,000) would not be a realistic solution; it would be only a repair job. For a fair comparison with the sea-level project, the alternate improvement program should include a cost estimate for the Third Locks Project modified to include a Pacific terminal lake based on more reasonable lock sizes. The terminal lake plan

estimate, furthermore, should not be balanced, unfairly, with the costs of protective features against modern weapons when the leading authorities admit there is no effective defense against such weapons. In brief, the relative value of each case should be fairly stated with parallel tables of unit costs so that the best canal can be built at Panama.[130]

The naval aspects of the present canal question have been well summarized by Rear-Admiral D. E. Barbey, Commander of the Caribbean Sea Frontier, when he stated that the United States has a two-ocean navy large enough to permit reinforcements to be sent around Cape Horn, that their is little likelihood of meeting a first-rate naval power in the foreseeable future, and that the Panama Canal has become a primary waterway for merchant ships in time of peace and a secondary route for critical raw materials in time of war. He minimized the probability of any enemy making a major effort to destroy it. "Why," he asked, "should they waste an atomic bomb on the Godforsaken Canal Zone, when they have New York Harbor as a target?"[131]

The military aspects for Admiral Barbey's thesis have been supported by Lt.-Gen. Leslie R. Groves, former head of the Manhattan Atomic Bomb Project, who has also predicted that in a future war the first attack on the United States would be "an atomic attack on New York."[132] General Groves further emphasized that until effective international control of the A-bomb is established the only protection is to keep the A-bomb away by means of a "well-balanced, effective, military strength." From this it follows that the only "security" for any type of canal project across the Isthmus depends on the combined industrial and military might of this nation and not on the inherent merits or physical features of the canal.

When the present confusions about "vulnerability" and "security" engendered by the atomic bomb are cleared away, and when these terms are understood in better perspective, the way should be open for a practical solution of this great problem as determined by the functional needs of the Panama Canal as a navigable waterway.

A. Casagrande,[133] M. ASCE.—The prompt publication of the results of these comprehensive investigations is an invaluable service to the profession. Much of this work will also prove of great value to other engineering projects. In this discussion the writer wishes to elaborate on the question of safe excavation slopes in the Cucaracha formation, which is one of the topics in the seventh Symposium paper, by Messrs. Binger and Thompson. The writer became acquainted with this problem officially in 1940; and, during the subsequent studies under Public Law No. 280 (Seventy-ninth Congress), he concurred in the conclusions as to the slopes in the Cucaracha formation, believing at the time (and believing still) that they are the best that could be reached on the available evidence and knowledge of the behavior of this material. It has been ques-

[130] "Let Us Build the Best Canal at Panama," by H. H. Little, *Journal*, Am. Soc. of Naval Engrs., November, 1946, p. 560.

[131] "Can We Defend the Panama Canal?" by Sidney Shalett, *Saturday Evening Post*, October 9, 1948, p. 162.

[132] *Cosmopolitan*, January, 1949, p. 41.

[133] Prof. of Soil Mechanics and Foundation Eng., Graduate School of Eng., Harvard Univ., Cambridge, Mass.

tioned during these investigations whether long-time effects may reduce the shear strength of the Cucaracha as a result of very slow swelling caused by reduction in load. This possibility received recognition in certain proposals by the Special Engineering Division which were briefly as follows:

(*a*) Install telltale devices to observe movements of the Cucaracha and from these evaluate the action taking place and adopt corrective measures where called for.

(*b*) Undertake long-range field and laboratory studies of the long-time effects in the Cucaracha formation when project authorization is given by Congress. Until the sea-level canal would be opened to traffic, there would be a period of 10 years or more for such studies.

In the analysis of this problem it seemed agreed by all concerned, including the consultants, that with the proposed slopes forewarning of such slides as might occur would be given by observable evidences which would permit remedial action (unloading), and that it was unlikely that such slides would involve great quantities of material moving with rapidity into the canal. Even if it is assumed that rapid movement would develop, the wide cross section of the canal prism would admit a large volume of material without causing closure of the canal to traffic.

Since the termination of the active studies by the Special Engineering Division in mid-1947, the writer has become increasingly concerned over the lack of knowledge of the long-time effects as they bear ultimately on the stability of the Cucaracha slopes.

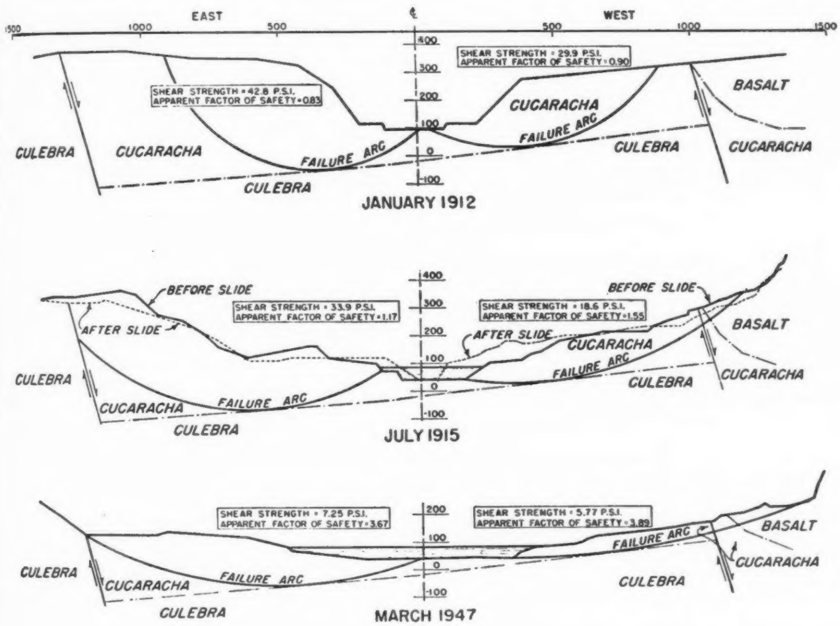
Long-Time Effects Influencing Stability of Slopes in Cucaracha.—The Cucaracha clay-shale is so difficult to test in the laboratory that the results of strength tests on this material have so far been of limited value. One was obliged, therefore, to rely on empirical rules derived from the behavior of the slopes and on the results of analytical studies of such slopes. Of special importance in these studies was the analysis of a "model slope" which has not failed, and of another slope which failed in 1907.

In Fig. 118[134] the cross sections through the Culebra slide areas are shown for three different dates, January, 1912, July, 1915, and March, 1947. When comparing these profiles (together with numerous photographs and a detailed description of the slides contained in the report by the National Academy of Sciences[135] and in unpublished reports of the Panama Canal), one is struck by the extraordinary reduction in effective shear strength (that is, the average shearing resistance along the probable failure surface) which has gradually developed over many years. For example, in January, 1912, the East Culebra slope, at the station shown in Fig. 118, had an effective shear strength of 42.8 lb per sq in. and the west slope, one of 29.9 lb per sq in. Still higher values can be computed for earlier construction stages, since substantial sliding had already been taking place in 1911. By July, 1915, the effective shear strength had

[134] "Report of the Governor of the Panama Canal Under Public Law No. 280, 79th Cong., 1st Session," Annex 4, Fig. 6.

[135] "Report of the Committee of the National Academy of Sciences on Panama Canal Slides," *Memoirs of the National Academy of Sciences*, Vol. XVIII, Washington, D. C., 1924.

dropped to 33.9 lb per sq in. and 18.6 lb per sq in. for the east and west sides, respectively. During the period since 1916 there has been no major slide. In 1940 the writer witnessed very slow movement toward the canal along the banks of the west side which would indicate that the computed effective strength of 5.77 lb per sq in. (Fig. 118, March, 1947, west side) would correspond to a factor of safety barely above 1.0.



Notes:

1. Shear strength shown is that required for stability of slope under conditions illustrated.
2. Apparent factor of safety is determined for slope using strength of Cucaracha as selected for new slope designs. Actual factor of safety was less than 1 until movement stopped.
3. P. S. I. denotes "pounds per square inch."

FIG. 118.—SLIDE STABILITY ANALYSIS, EAST AND WEST CULEBRA, AT OLD CANAL STATION 1785 + 00

Even if it is assumed that the early slides had already affected the clay-shale as far as 1,000 ft inside the face of the slopes, it would be remarkable that the effective shear strength of such disturbed material would continue to drop in the course of 35 years quite gradually to about one fifth or one sixth of the value that governed the stability of the slopes in January, 1912. However, the writer believes that in 1912 at least one half of the mass bounded by the underlying Culebra and on the east and the west by faults, as shown in Fig. 118, was not yet disturbed by the slides and that intermittently additional parts of the mass became involved in the movement. If the assumption is made that the strength characteristics of the undisturbed material have not considerably changed with time and that they are equal only to those governing

the slopes in January, 1912, then it can be shown that the mass should have come to rest with much steeper slopes than those existing today.

Based on the foregoing considerations the writer is forced to conclude that the strength not only of the disturbed material, but also of the undisturbed material, has been gradually and very substantially decreasing in the course of many years as a result of the reduction in normal stresses and the increase in shear stresses.

Many examples could be cited to show that in clay-shales and stiff clays any substantial reduction in load due to excavation is followed by a long period of swelling. Whereas on this project the engineer's concern is the reduction in strength, the volume increase due to swelling is of importance in connection with several large earth dam projects along the Missouri River where extensive deposits of clay-shales form the foundations for the structures. For example, the Bearpaw shale at the Fort Peck spillway has been causing a continuous heaving of the spillway chute pavement with a maximum of about 2 ft since 1936, and the heaving is still progressing.

Whether the slow reduction in strength of the Cucaracha is caused by an ordinary swelling process which follows the theory of consolidation, or whether this reduction is the result of molecular adjustments to the reduced normal and increased shear stresses which gradually weaken the cohesive bonds without significant swelling of the entire mass, is a question that will require much research along the lines already contemplated before it can be answered. Such research should also answer the question whether measurable plastic deformations precede, for a considerable time, any major movement—a likely reaction for such a highly colloidal material. It may well be that by such observations the possibility of additional movements could be determined so far in advance that necessary flattening of a slope could be undertaken in time to prevent a slide. It is conceivable that slopes could be designed to be safe for a period of, say, about 20 years, with the intention of flattening when the need is indicated by analysis of the observed deformations. Such a proposal is unorthodox, but it is what (for all practical purposes) has been done since about 1914 on the slopes shown in Fig. 118, apparently without any special difficulty. If such an approach were followed in the design and construction of a new or improved canal, it would result in an earlier completion of the canal and would also have the advantage that additional flattening of slopes would be carried out only if, when, and where needed. The latter advantage is important because the stability characteristics of the Cucaracha seem to vary widely.

Comments on Model Slope and Old Slide Used as Criteria for Undisturbed Shear Strength.—The presence of a layer of relatively strong and pervious ash flow in the model slope indicates the possibility that the sequence of various layers is not identical with that in the Culebra slopes. Furthermore, even though the borings indicate layers of the soapy phase of the Cucaracha, it is not the mere presence of this material but its relative position to the stronger phases of the Cucaracha which determines the over-all resistance to sliding. It is not difficult to conceive a distribution of strong and weak layers, or of faults and other irregularities, such as to interrupt a continuous shear surface

through the soapy phase so effectively that the total resistance of this slope may be much greater than that of the Culebra slopes. If this slope had a real factor of safety very much greater than unity (which is a possibility), there would apparently be no rational basis for using this slope for derivation of those strength characteristics which govern much weaker slopes such as those shown in Fig. 118. However, for the purpose of the recent studies this procedure appeared to be the best that could be followed at that time.

In regard to the 100-ft cut that failed in 1907 with a slope believed to have been 3 vertical on 2 horizontal, the writer understands that the stability analysis of the slide checked the design criteria for a factor of safety of unity (see Fig. 110). If one takes into consideration the probable time effect, one is forced to the conclusion that, to begin with, this slope must have been weaker than the slopes illustrated in Fig. 118, and very much weaker than the model slope which is still standing. In the writer's opinion the tacit assumption that for the purpose of analysis these slopes have similar strength characteristics is not tenable.

The Cucaracha clay-shale is so thoroughly slickensided that the usual differentiation between undisturbed and disturbed material can scarcely apply. Considering the extreme weakness of the finest-grained phases of the Cucaracha, and having in mind the rather rough topography of the Canal Zone, the writer is inclined to believe that some of the Cucaracha which has been affected by slides as a result of the construction of the canal had been exposed to excessive shear deformations at some previous period and, therefore, must be considered as disturbed material. Whatever the causes of the slickensides, they represent disturbance of the material.

Many of the observed slides have moved slowly, showing only a small reduction in the effective shear strength before and after each movement. This condition is particularly significant when compared to the large difference between the maximum and residual (after failure) strength values obtained in all laboratory tests on Cucaracha because it makes it appear probable that the resistance of the banks to sliding had already the character of residual strength when the cuts were made. (This large difference was found both for the tests in the Canal Zone and for those made in the laboratory at Harvard University in Cambridge, Mass. The latter showed that the residual compressive strength in all tests on Cucaracha was about one half of the compressive strength, regardless of the time of loading.)[136] Adding to these observations the important time effects, the writer cannot escape the conclusion that the strength characteristics of the Cucaracha clay-shale are not similar to those that can be expressed by the Coulomb equation with constant c-values and ϕ-values. In addition, the basis on which these values were determined is open to objections.

Conclusion.—Having thus critically reviewed the method of arriving at the slopes in the Cucaracha, the writer reiterates that the proposed design curve represents the best that could be accomplished with the tools and the knowledge available. The writer believes that the Special Engineering Division would not have been justified in spending more money on these investigations even if the

[136] "Research on Stress-Deformation and Strength Characteristics of Soils and Soft Rocks Under Transient Loading," *Bulletin No. 31*, Soil Mechanics Series, Cambridge, Mass., June, 1948.

necessary additional time had been available. However, as soon as construction of a new or improved canal is authorized by Congress, the additional investigations on the stability of slopes in Cucaracha should be carried out, with special attention to the time effects. As recommended by the Special Engineering Division, it would then be necessary to explore and study thoroughly the materials in each slope, by additional exploratory borings as excavation of the slope progresses, with the purpose in mind that additional flattening of the slope will be undertaken if it is found that in any place the strength falls below expectations.

In addition, the writer recommends extensive observations on the pore-water pressures in the Cucaracha formation, and on the possibility of reducing these pressures by drainage measures (wells and tunnels) for the purpose of increasing the stability of slopes. The effect of time on the shear strength should be investigated also by long-time laboratory tests. Although this is a very difficult task, every effort should be made to bridge the large gap that now exists between the results of laboratory strength tests and the strength characteristics that govern the stability of slopes in the Cucaracha.